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ELECTRONICS FOR A ROCKET BORNE QUADRUPOLE CLUSTER ION MASS FILT--ETC(U)

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ELECTRONICS FOR A ROCKET BORNE QUADRUPOLE CLUSTER ION MASS FILTER

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Electronic circuits have been developed to control a rocket borne quadrupole mass filter intended for measurement of ion clusters. The low altitude instrument was designed to measure negative or positive ions in the high pass or the band pass modes. Its range extended to 255 amu. Digital control of the bias and the quadrupole excitation signals was maintained during the flight through a program stored in an EPROM. A manual control unit which could be substituted for the EPROM provided flexibility during laboratory experimentation and calibration procedures.

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TABLE OF CONTENTS

TABLE OF ILLUSTRATIONS

I. INTRODUCTION

A rocket-borne low altitude quadrupole mass spectrometer has been developed by the Aeronomy Division of the Air Force Geophysics Laboratory. The helium cryopump, the structures of the mass filter and the housing for the instruments have been designed and constructed by the AFGL. The electronic systems for the spectrometer and for the ground support equipment have been developed and constructed by the Electronics Research Laboratory of Northeastern University.

The Cluster Ion Mass Spectrometer shown in Figures 1 and 2 was designed to measure ambient positive or negative ions. In both modes, the instrument could be operated as a band pass or a high pass mass filter. The range covered by the quadrupole filter extended from 1 to 255 amu. To cover that range an RF generator operating at 2.3 MHz with a capability of peak amplitude in excess of 700 volts was used to excite the two sets of quadrupoles of the instrument. Twelve milliseconds were allowed for each amu domain. During that time, the quadrupole excitation signals completed a 16 level staircase sweep centered around the nominal voltages appropriate for that mass unit. The generation of the quadrupole excitation signals and bias voltages was digitally controlled.

The spectrometer flight control information was stored in an erasable and electrically programmable read-only-memory (EPROM). Eight programs could be sequentially selected during the flight. The number of times that each program was repeated could be set before the final

elevation of the sounding rocket. This required a simple wiring change of a connector provided for that purpose.

An electrometer logarithmic current to voltage converter was employed to process the data from the electron multiplier. These circuits were referenced to the anode potential of the multiplier. To translate the data to the vehicle potential, voltage to frequency converter and an optoisolator were used. At the vehicle potential the signal was converted into analog and PCM signals for transmission over a PCM/FM/FM telemetry link. The spectral data was sampled and converted into a 10-bit binary word once every millisecond. A complete frame of the PCM signal was devoted to each amu domain. Aside from the nine 10-bit spectrum data words, the frame also contained information on the mode of operation, the status of the bias signals and amu identification.

To facilitate laboratory experimentation and calibration procedures, a control unit to replace the flight EPROM was designed. This unit enabled the operator to set via keyboard the limits for a sweep through a range of amu's, to control the ratio between the ac and the dc components of the quadrupole excitation signal, to choose a mode of operation and to adjust the bias voltages. Also, a simple PCM decommutator was included which allowed the operator to display the PCM data in an analog form. Selection and display of a single amu out of a sweep over several amu domains was also possible. Seven segment and single LED indicators were used to verify the keyboard entries, to display the selections and to confirm the mass spectrometer responses to the given commands.

II. MASS SPECTROMETER ELECTRONICS

A. Digital Control

Control over the operation of the Cluster-Ion Mass Spectrometer during a flight was exercised by a digital control unit. A number of preprogrammed digital signals were converted into the necessary analog voltages to provide bias and excitation signals for the mass filter. Also included in this general group were circuits for data conditioning and for the generation of a PCM signal. Detailed description of this unit has been published as a scientific report AFGL-TR-78-0106 listed in the "Related Contracts and Publications" section of this report. Therefore, only a brief summary of the unit will be presented in the following paragraphs.

The flight instructions for the mass spectrometer were stored in a one kilobyte EPROM. Eight bytes were used to define one complete set of commands. Two 12 bit instructions designated the limits of an amu domain through which the mass filter was to sweep. An eight bit instruction controlled the ratio between the dc and the RF components of the quadrupole excitation signal. Three bits were used to set the draw-in potential of the cone where the inlet orifice was located. The positive or negative ion and the high pass or band pass modes of operation were set by two additional bits. The remaining bits were used for housekeeping instructions, as spares or, for the convenience of design, were not utilized at all.

Past experience has shown that one program, which was usually repeated throughout the flight, required less than 16 sets of instructions. Therefore, this unit was designed to accomodate up to eight different

programs of that length. Only seven jumper wires between the pins of a connector were needed to determine the number of times each program was to be repeated during the flight before advancing to the new program. The connector could be wired and installed just before the final elevation of the sounding rocket, when the flight trajectory has been confirmed.

Although not directly associated with the control of the mass spectrometer, PCM and data conversion circuits were included within the control unit. The data from the mass filter section of the instrument arrived in the form of a pulse train whose repetition frequency varied between 20 and 70 kpps. A frequency-to-voltage converter produced an analog signal varying between zero and minus ten volts. Inverted and halved, the analog signal was sent to the subcarrier oscillator of the telemetry system. The original negative analog voltage was converted into a digital signal and transmitted over a PCM/FM/FM link.

The PCM NRZ-L data was transmitted at 10 kHz rate. One complete frame of 120 bits was assigned to transmit data associated with each amu. It started with a 16-bit frame synchronization pattern which was followed by a 5-bit status monitor word and a 9-bit amu identification word. The remaining bits were divided into nine 10-bit spectrum data words. Complete synchronization was maintained at all times between the PCM and the control functions of the mass filter. The spectral data was sampled once every millisecond and 200 μs before the MSB of the binary word representing that sample appeared in the PCM pulse train. One millisecond before the MSB of the frame synchronization

pattern appeared, a sync pulse signaled the start of a voltage sweep through a new amu domain. At this time, if any changes in the control functions of the instrument were required, the control unit provided the necessary information. Any transients in the analog control voltages caused by the updating process had 3.8 milliseconds to settle before the next meaningful sample of the analog signal was converted into the digital word. During this time the D/A converter generating the sweep signal in the analog section of the instrument continued to be updated every 750 μs. Therefore, in these 3.8 ms, the sweep staircase signal advanced through five out of the sixteen levels assigned to one amu domain. Thus the nine data words in the PCM pulse train covered only the last 75% of that interval. By an appropriate offset bias the peaks of the mass spectrum were shifted into the intervals where the data was sampled. This offset bias could be introduced either in the sweep generator section of the instrument or by manipulating the four least significant bits of the control word specifying the start of an amu domain. In either case, the data transmitted as an analog signal was not effected and always covered the full amu domain.

B. Analog Control of the Quadrupole

The immediate control over the quadrupole excitation signals was exercised by analog circuits. These circuits in turn received commands in a digital form from a control unit programmed for the flight. The D to A interface and the analog control circuits are shown in Figure 3.

The digital control over the amplitude of the dc and the RF excitation signals was maintained through the two D/A converters (U1 and U2). The twelve bit D/A converter (U2) established the amplitude of

these signals, while the multiplying DAC (U1) maintained the desired ratio between the RF and the dc components. The required adjustments of the offset and the amplitude were provided by the amplifier circuit (A3) which followed the D/A converter. The same circuit had the provision (U3B) to increase the output signal during the high pass filter mode of operation. This allowed the same digital designation to be used for the cut-off mass in the high pass mode as in the more prevalent band pass operation.

Inverted and readjusted to establish a nominal RF to dc ratio by A4, the output of A3 became the control signal for the RF generator. Also, the A3 signal was used as the reference voltage for the multiplying ratio control DAC (U1). The two MSB's of this unit were held at +5 volts while the rest of the inputs were used to establish a fine control over the ratio. The output signal of the DAC was used to generate the +DC and the -DC voltages for the mass filter. The quadrupole bias (Q1) was injected as a common mode voltage through the output amplifiers A5 and A6. During the high pass filter mode of operation, the DC component was reduced to zero by a signal at the TOT ION terminal. The FET gate U3 increased the gain of A3 and reduced the voltage at the two MSB's of U1 to zero. Of course, the LSB's of U1 were also set to zero by the digital control unit.

C. Bias Circuits

Four bias voltages were provided to the main filter and associated structures. The conical front end of the instrument containing the sampling orifice was biased with respect to the vehicle by the "draw-in front end bias" (FEB) potential. For this purpose, sixteen preset

voltage levels in the range from +40 to -20 volts could be selected by the flight program. The remaining three bias voltages Q_1, Q_2 and ACC were floated on this potential. These were the bias signals for the rods of the mass filter, for focusing rods located between the orifice and the main quadrupole, and for the accelerating electrode respectively.

The bias circuits are shown in Figure 3. The amplifier A1 generated the FEB signal. The polarity and the amplitude of that bias signal were determined by the status of the multiplexer circuit U1. When the control signal at D of U1 was high one of the Rp resistors (not shown) was connected to pin 5 of A1. A low signal at terminal D connected one of the Rn resistors to the amplifier. In the former case the output of A1 was a positive voltage while in the latter case either a positive or a negative output was obtained. When the selected resistor was returned to ground a positive FEB was generated. A resistor returned to a positive reference caused a negative FEB. The selection was accomplished by the appropriate signal at B_0, B_1 and B_2.

The FEB signal had to pass through two relays before reaching the cone of the instrument. The relays isolated and protected the amplifier from vehicle and/or instrument ground during the laboratory tests and during the initial phases of rocket flight. The latching relay (S_2) provided protection mainly during the testing phase. Before the flight it was latched into ON position. Then S1 interupted the signal flow to the cone, which at that time was shorted to the vehicle ground by the cap which sealed the entrance orifice of the mass filter. Only after the cap has been removed and the HV and RF

circuits have been activated, the relay allowed the FEB signal to reach the cone.

The same signal that controlled the selection of Rp/Rn resistors determined the polarity of the other three bias signals. Transistors Q_1 through Q_4 formed a switch which selected the polarity of the voltage supplied to the current source Q_7 and Q_8. The current source was used as a power saving measure. The current through the diodes CR7 through CR9 generated the ACC and Q1 bias signals.

During the testing and the calibrating process of the instruments, it was determined that in the negative ion mode the bias level to the focussing rods (Q2) had to be one half the level of Q1 bias. In the positive ion mode both the Q1 and the Q2 biases had approximately the same amplitude. To generate the Q2 bias the simple voltage divider circuit consisting of CR 22, 23 and R47, 48 was used. The three biases Q1, Q2 and ACC were referenced to the front end bias signal.

The monitor circuits consisting of amplifier A2 and the associated components converted the bipolar bias signals to the positive zero to 5 volt signals for transmission through telemetry.

D. RF Generator

A modified Hartley Oscillator was used to generate the RF component of the quadrupole excitation signal. The oscillator operated in the vicinity of 2.3 MHz when loaded with the 81 pF capacitance presented to the circuit by the two sets of rods of the prefocusing quadrupole and the mass filter. In order to cover the ion clusters up to 255 amu at that frequency, the circuit had the capability to drive

the two quadrupoles with nearly 700 volts of peak signal.

The oscillator and its associated control circuits are shown in Figure 4. A 40-volt battery was used to supply power to the oscillator. The supply voltage was pre-regulated to 37 volts by the series pass transistor TIP 142. This was done to avoid a possible secondary breakdown in the power transistors of the oscillator by an excessive voltage of a power supply. Also, for protection of the same transistors a current sensing shut-down circuit consisting of two-741 operational amplifiers was employed. Whenever the current exceeded a preset level of approximately one ampere the circuit interupted the base drive to the oscillator transistors. The ensuing reduction in the collector current released the base drive, which in turn increased the collector current once more. The resulting oscillation continued until the base drive originating in the RF control circuit was reduced. This type of current limiting generated a transient which ensured a restart of the oscillator. The more conventional current limiting circuits which were tried had the tendency to stop the RF oscillator while still permitting considerable current to flow.

The control over the amplitude of the RF signal was exercised by a CA3140 op-amp providing the base drive current to the power transistors. This amplifier received signals from the RF control circuit of the sweep generator and from the RF feedback circuit employing another CA3140 operational amplifier. The RF feedback signal was derived from one of the windings of the output transformer. A capacitive divider attenuated the signal which in turn was processed by a dc restoration circuit followed by an integrator.

This approach had an advantage over the conventional peak detector where the feedback signal was derived either from a separate winding or from a tap in the output winding of the transformer. In both cases the harmonic content of the derived signal was high. The peak detector followed the distortion of the signal which varied with the output level. This resulted in a nonlinear control of the RF signal. The harmonic content of the signal derived directly from the resonant output circuit was greatly reduced. The integrator further removed any spurious disturbances. Since the average voltage of the signal in the dc restoration circuit is proportional to the peak of the RF voltage, an effective control over the amplitude of the RF signal was maintained. The nominal ratio between the RF and the dc was established by the two resistors (16.2K and 20K) connecting the RF control and the feedback signals to the summing junction of the oscillator driver operational amplifier. The feedback signal when isolated and attenuated by the -741 circuit also served as the RF monitor signal.

E. Data Circuits

The electron multiplier current was measured by a logarithmic electrometer similar to the circuits that have been used to process multiplier outputs in earlier mass spectrometers flown by AFGL. In this Cluster Ion Mass Spectrometer application the electrometer and its associated circuits were referenced to the high voltage potential of the multiplier anode. Therefore, to translate the data to the vehicle potential, a voltage to frequency converter and an optoisolator circuit was employed.

The electrometer and the data conversion circuits are shown in Figure 5. The logarithmic current to voltage converter was constructed using a MOSFET operational amplifier (A1) with bias currents at least two decades below the minimum current (10^{-12}A) to be measured. One half of a dual transistor (Q1A) produced the logarithmic current-to-voltage conversion. The other transistor of the pair (Q1B) was used to establish the customary temperature independent pivot point. To set this operating point current, an operational amplifier (A2B) produced a constant voltage (within the stability limits of the -15V supply) across R_2. Thus a constant current was established in the collector circuit of Q1B. With this stable operating point set, temperature compensation at other current levels was provided by the silicon resistor R5. This resistor in conjunction with R6 and R4 also established the necessary gain in the log amplifier to provide a one volt change in the output for each decade of the input current. Six decades of current could be accomodated by this circuit. The lower limit of the input current was set by the Q2 circuit.

The negative output voltage of the log amplifier was translated into the positive voltage range by the A2A circuit. The lower limit of the signal presented to the voltage-to-frequency converter (U1) was set at +2 volts. The converter was adjusted to produce approximately 20kHz at this input level. Each additional volt of the input signal increased the output frequency by 10kHz. A CMOS inverter/buffer served as a driver for the optocoupler U3. A single transistor (Q3) circuit was used to amplify the output signal and to drive the cable connecting the mass spectrometer to

the signal processing circuits located in the control section of the instrument.

F. Power Control and Supplies

Four separate supplies were used to provide power to the instruments. Two of the units supplied the high voltages needed by the electron multiplier and the positive ion target. The low voltages for the quadrupole control and excitation signal circuits were obtained either directly from a battery or through a multi-output dc-dc converter. The needs of the floating electrometer circuits were supplied from a separate dc-dc converter with a high input-to-output breakdown rating. Magnetic latching DPDT relays were used to control the power transfer from external or internal sorrces to the power supplies.

The positive ion target and the electron multiplier voltages were obtained from Venus Scientific, Inc. supplies K-30Z and MG-12 respectively. The output levels of both supplies were controlled by the circuits shown in Figure 5. While the K-30Z required external control to set the output voltage, the remote capability of the MG-12 was utilized for accessability and convenience only.

The low voltage needs were supplied by the dc-dc converters shown in Figure 6. To reduce voltage transients generated by the power supply, an oscillator and the pulse shaping circuits (U1 and U2) drove the low power inverter stage (Q1, Q2, T1) at 25kHz. The output of the transformer T1 provided the drive to the power output stage (Q4, Q5, T2, T3). To limit the number of secondary windings per transformer as well as for packaging purposes, two potcore output transformers were used. Since a pre-regulator (U3,Q3) was employed to supply the input power

to the inverter, most of the output voltages did not require additional regulation. Only the ± 15V outputs supplying the more critical circuits were provided with additional regulators. Also, where needed, on-board regulators were included in other parts of the instrumentation. For example, the digital control and data processing circuits contained their own ± 15V and + 5V regulators which were supplied from the unregulated ±20V output of the main power supply.

External power to the dc-dc converters was supplied through S1. The high voltage supplies could be activated only when a voltage was present at the output of S2. The same relay (S2) provided means to switch between the external and the internal power sources. The RF oscillator power was controlled by S3 and S4. The former selected external or internal power source operation while the latter turned the RF excitation on and off. Provisions were included to activate the RF oscillator and HV circuits with a positive pulse at the "timed on" input. This pulse was generated by the vehicle timer after the rocket burn has been completed and a relatively vibration-free flight has been achieved. At the end of the flight the instrument could be turned off by another pulse from the vehicle timer applied to the "timed off" terminal. The S5 relay connected the negatively charged capacitor C2 to the control coils of the S2 and S3 relays to switch them to then nonexisting external power source.

III. MANUAL CONTROL UNIT

A. Overview

A digital instrument was constructed which allowed the operator to exercise manual control over the operation of the mass filter. Its main purpose was to provide flexibility in laboratory experimentation and calibration procedures. It also provided means to test the operation of the flight control unit, to decommutate the PCM signal and to convert it into an analog form.

The control commands were entered via a keyboard. The operator could select any amu region, within the capability of the instrument, which the mass filter had to scan. Ratio between the ac and the dc components of the quadrupole excitation signal, the modes of operation and the bias voltages could be manipulated at will. A provision was included to select and to convert into an analog form any one amu domain within the sweep range. The internal clock of the flight control unit could be substituted with an external one whose frequency could be varied in binary form from 80kHz to 1.25 kHz.

The selected parameters were displayed. The amu's designating the limits of a sweep, the ratio and the selected single amu to be extracted from the PCM signal were indicated by seven segment LED displays. The bias selection and the mode of operation were displayed by single LED indicators. Two sets of these indicators were used. One displayed the selected bias and the mode of operation; the other displayed the same information but the signals were derived

from the PCM data. Thus the response of the instrument to a given command could be verified.

The circuits of the manual control unit could be subdivided into three groups. The first group translated the keyboard entries into binary commands. These commands were either relayed to the flight control unit or to the other circuits of the manual controller. The second group consisted mainly of various LED indicators and drivers. The third group was dedicated to handle the PCM data and to convert it into an analog signal for recording and display.

The keyboard continued numerical entry keys ZERO through F and a number of function keys. Three digit decimal numbers were used to enter data designating amu or ratio. A hexadecimal number was used to enter the last four LSB's which represented the 16 levels within one amu domain. Also, a hexadecimal entry controlled the bias and the band pass/high pass status of the mass filter. Numbers 0 through 7 selected appropriate bias levels in the band pass mode of operation while numbers 8 through F set the same bias levels in the high pass mode. Positive or negative ion operation was selected by a separate key in the function group. Other function keys routed the entered data into appropriate registers for execution and display.

B. Control and Display

The circuit drawings of the manual control unit are shown in Figures 7 through 11. The first three drawings show the control, the display and the interface with the EPROM circuits in the flight

control unit.

The necessary housekeeping waveforms and the external clock for the flight control unit were generated by crystal oscillator and a counter (U28,U29). The numerical entry's from the keyboard (X1 through Y4) were incoded into the hexadecimal code. When the function key • (DOT) was depressed before a numerical entry, the encoded digit was stored in U12. Otherwise the encoded digits were stored in latches U13, 14 and 15. The outputs of these latches were converted into an eight bit binary number by U10. Also, the outputs of all latches were routed to the keyboard display for verification (Figure 9). Three seven segment and one hexadecimal LED displays were used to accomodate data from U13, 14, 15 and U12 respectively. Whenever data was to be entered into U12 by first depressing the DOT key, the seven segment displays were blanked out. Only BCD numbers were valid entries into the other three latches whose outputs were converted into binary code. Therefore, to alert the operator to an impending error, an invalid entry was also indicated by blanking the display. Once a valid data entry has been made, it could be transferred by depressing an appropriate key into the output latches U1 through U5. Thus, the STOP key loaded U1 and U2 with data which set the end point of the sweep through the amu range. If instead the ratio key were depressed, it would have loaded the eight MSB's of the entered data into U4 thus converting it into the ratio control information. The data stored into an output circuit was also latched as a decimal/hexadecimal number into an appropriate display (Figure 9) to indicate the operating status of the mass spectrometer.

Each time the flight control unit ended an execution of a given instruction set the data stored in the output latches of the manual control unit was sequentially transmitted to the output lines of the now replaced flight EPROM. The control of that sequence was derived from information originating in the address lines of that EPROM.

The circuits responsible for the generation of the various latching and other control signals are shown in Figure 8. Bounce eliminators (U23,30) were used on all the function keys except the clear signal key. The command to latch data into U12 and to blank the BCD keyboard display was generated by U21 connected to toggle everytime the DOT key was depressed. The latch signal appeared at pin 2 of U20 (2U20) when the encoder (12U17) generated data ready signal. At the same time the counter (U34) which generated the latching signals for the U13, 14 and 15 circuits was inhibited. The blanking command emerged at 15U32. The flip-flop (U21) was reset and thus the blanking was removed when any of the keys transfering data from the keyboard registers to the output latches were depressed.

The circuit group U7, 8, 9 and 35 generated the sequence (S1 through S6) in which the data from the output latches were made available to the flight control unit. The control signals (A0E, A1E and A2E) to generate the sequence were the three LSB's of the EPROM address which in turn were synchronized with appropriate latching signals in the flight control unit. The supply voltage for U7 also was obtained from the flight unit. This arrangement

together with the resistor network (U9) and the tristate capability of the output latches protected both the flight unit and the manual control unit from a possible damage when power to one of the units was disconnected.

The selection of an internal or external clock operation and the provision to stop the sweep on a selected amu were implemented by the U31 and U33 circuits. INT/EXT key toggled U31B producing a ONE or ZERO at 10U33 and forcing the flight unit to operate on external or internal clock respectively. The HOLD key toggled U13A. When pin 1 of 13A was in the high state, command to go into the external clock operation was transmitted to the flight control unit, while at the same time external clock was inhibited. This occurred only when A1E address line of the EPROM was high. This situation in turn existed only during the updating process when the amu sweep was returned to the starting point. Therefore, the flight control unit stopped within the amu domain displayed as the starting point of a sweep.

U32 served as a LED driver to monitor the status of the system. The LED's indicated whether the systems were running or stopped, whether it was on external or internal clock, whether the mass spectrometer power was turned on or off, and whether the PCM system decommutator was synchronized.

C. Data Circuits

The PCM decommutator and the data circuits are shown in Figures 10 and 11. The PCM train of pulses entered shift register (U3 through U7) which was driven by an inverted clock from the PCM generator of

the flight control unit. Comparator (U12 through U15) was used to detect the frame synchronization. Once the frame synchronization pulse was generated, data present in the first three shift registers were transferred into the latches (U8 through U11). The spectrum data were stored in U8 and updated every millisecond with the new information carried by the PCM signal. The output of this register was continuously converted into an analog signal by the AD7521 unit.

To select a single amu for display on a chart recorder, the information identifying that unit was transferred from keyboard latches into U22. The comparator U16 and 17 generated a pulse whenever a match occured. The strobes and their timing required to control the latches were generated by the circuits of Figure 11.

The incoming PCM clock was converted into a series of narrow pulses centered within the clock period by the monostable U36. These pulses in conjunction with other waveforms were used to generate strobe signals. This allowed sufficient propogation delay time for the circuits driven directly by the clock waveform to settle before their data was transferred; thus any "race" problems were avoided. In coincidence with the frame synchronization pulse two strobe pulses were generated. One, the DATA strobe, latched the spectrum data into U8. The other, ID strobe, latched the status and the amu identification data into U10 and 11. It also generated, through 9U37, a pulse to dump a sample and hold circuit. Thes circuit (not shown in the diagrams) could be used, if desired, as a peak detector during the single amu selection

process. When in this single amu mode (2U27 low) the ID strobe was generated only during coincidence of the frame and the amu synchronization pulses.

The decade counters U31 and 32 monitored the number of spectrum data words to be latched into the U8 during a PCM frame. Reset was generated to clear the U8 register in the single amu mode after the nine words associated with that amu have been counted.

The circuit group U24 through U30 and D1, D2 and D3 displayed the selected amu when synchronization has been achieved. For that purpose a servo type binary to BCD converter was used. The latching amu identification bits A1 through A8 were compared with the binary count in U26. This counter as well as the BCD counter U28, 29 and 30 were reset by the ID strobe and then were driven from the same 80 KHz clock. When the binary count agreed with the amu identification word, the clock was inhibited. Both counters, the binary and the BCD, had the same count; thus the conversion was accomplished. The BCD number was displayed by the seven segment displays D1, 2 and 3.

Two additional counters, U33 and U38, were used to generate multiplexing signals for the various displays of the control unit and to detect loss of the PCM synchronization respectively. Both circuits are rather primitive and require no explanation. The manual control unit was packaged into a small metal suitcase and was powered from +28V external supply. The digital data latched into the storage registers was made available for further processing through interface connectors.

IV BALLOON CIMS

Preliminary work has been carried out on the definition and design of control electronics for a balloon borne mass filter. The filter, similar in principle to the rocket borne instrument, will measure ambient positive and negative ions in the stratosphere. Its range, however, will be extended to 1000 amu.

Some of the analog circuits developed to control the rocket borne mass spectrometer will be adapted for the new instrument. The circuits which may be used with only minor modifications include the various bias and monitor circuits and the sweep generator. The RF excitation generator may have to be modified for a two frequency operation. Some switching arrangement will have to be implemented to provide an RF signal above 3 MHz for a sweep through the lower amu range and to drop the frequency to one MHz for a sweep through the upper mass units. The basic design of the oscillator using the air core toroidal transformer and its housing will be maintained. Although the oscillator has been developed as a part of a masters thesis and was incorporated into the rocket borne instrument, a complete description of the unit could not be provided in time for this report. The thesis write-up will be completed during the follow-on contract and at that time will be issued as a scientific report.

The digital control and the data processing subsystems will be redesigned. The long duration of a balloon flight and the relatively slow changes in its environment offer an opportunity of

modifying the experiment based upon results currently being obtained. A microprocessor based control system provides the flexibility needed to control the instrument, to process the data and to furnish the facilities for an interaction with a ground based operator.

A microprocessor based control unit has been developed as part of an engineer's thesis. The complete thesis will be submitted in September, 1979, and subsequently will be issued as a scientific report during the follow-on contract. The μP based unit has been limited to provide only the basic control functions for a mass filter. A set of instructions allow the user to assemble various programs from a library of stored repertoires of modes and use them in a prearranged sequence during the flight. These programs then exercise control over the various bias signals, establish the range of amu's over which the filter has to sweep and sets the maximum time interval during which data may be accumulated into a counter within each amu domain. The time interval during which the data was collected, the data and some other pertinent information such as the real time and the outputs of some environmental monitors are then stored into a temporary memory. No provisions have been included for an interaction with a telemetry system or a bulk data storage system.

Independently of this control unit development, a study has been conducted by Dr. Stuart of Northeastern University to establish guidelines for an overall control system for the balloon borne experiment. The study has been presented as an informal eight part

report to the contract monitor. Therefore, only the recommendations and future work suggestions presented in the summary of the report are included below.

RECOMMENDATIONS

1. A standard flight-proven complete system with the addition of the microprocessor system should be flown so that the existing hard-wired controller can act as a back-up to the microprocessor.

2. One signal on the tone command link should be allocated to change-over from microprocessor to hardwired control.

3. The overall software system should be based on a simple run-to-completion executive.

4. All software tasks including the executive should be table driven and consist of a program in ROM and a data base in RAM, the data base being modifiable by operator intervention.

5. One signal of the tone command link should be allocated to RESET to return the microprocessor to the beginning of the executive program.

6. A standard teletype should be used as a ground terminal (this provides only start and stop bits in addition to standard ASCII).

7. For error control on the teletype link reliance should be placed principally on echo checking.

8. Operator interaction should be restricted to those modifications which can be implemented by changing a small number of bytes in RAM.

9. Recognition of an operator request should normally be by polling but in addition some form of recognition via interrupt or reset is desirable.

FUTURE WORK

The immediate task is to firm up the specification of the first flight unit. Some of the areas requiring attention are listed below:

1. An overall plan for address space use should be drawn up. Some addresses must be reserved e.g., those used for reset and interrupt purposes. There may be more than one person involved in coding and they will be concerned with address allocation. This obviously needs coordinating.

2. For similar reasons a plan for the use of interrupts is also needed. Correct priorities need establishing.

3. A decision should be made whether to include the noise protection scheme involving the inhibiting of reading during periods of low signal strength. It will complicate the interrupt scheme and could probably be left as a future refinement. The decision will depend upon the expected performance of the ratio link.

4. Precise requirements for the input to telemetry need defining. These should probably match as closely as possible those currently provided by the present hardwired system. There may however be complications. For example, if the TM requires continuous input for sync purposes the microprocessor system bus cannot provide it as it must be time shared with other tasks.

Quite a number of questions arise in connection with the recording of data. Consideration needs to be given throughout to maximizing the efficiency of memory use since as already noted this is a scarce resource.

5. The acquistion of the data from the mass spectrometer is the subject of a separate study as noted earlier. The range precision and format of what is to be recorded needs to be specified.

6. Four parameters are to be recorded along with the data - altitude, ambient temperature, vehicle/space potential probe and real-time clock. All need specifications for range precision and frequency of recording.

   The formatting and correlation with MS data needs defining.

   Interfacing should be examined, e.g., A/D converters may be needed in some instances which may or may not be provided by existing equipment.

   Initialization should also be examined, e.g., for the real-time clock.

7. Five parameters are to be monitored - pump pressure/ion pump, cryogen level, cryogen vapor flow, package temperature and package pressure. The form of monitoring needs defining. Typically each could be tested to check that it is within a prescribed range, in which case the ranges need defining.

   Action to be taken if an out of range value is encountered needs defining. Possibly this could be recorded and sent to the terminal by the equipment checkout routine. Again range precision and format of each parameter needs defining. It would also need identifying, e.g., by assigning a 2 letter identifier to each

parameter. The identifier could be stored in the program and transmitted to the terminal with the value of the parameter concerned. Much depends here upon what facilities are available to correct such faults.

8. The mass spectrometer can be operated in various modes such as positive or negative ion, total ion etc. These may be selected from the ground. It is also possible to control to some extent other parts of the equipment e.g., by switching motors or heaters etc. Three methods are available - tone command "ASCII push button" and software. All such operations need listing and specifying. If it merely entails assigning one of the tone commands, the system currently under discussion is not affected. If ASCII push button is used, code words should be assigned and I/O ports allocated. Any interfacing hardware should be defined. If software is involved, the routines should be specified and developed.

9. The parameters to be checked by the initialization routines need defining. This routine should be concerned principally with hardware operations. Software initialization should be confined to that needed by the executive and anything needed by the overall system (e.g., the real-time clock). The individual tasks should take care of their own initialization as far as possible.

PERSONNEL

A list of the engineers and technicians who contributed to the work reported:

J. Spencer Rochefort, Professor of Electrical Engineering, Principal Investigator.

Robert D. Stuart, Professor of Electrical Engineering, Engineer.

Raimundas Sukys, Senior Research Associate, Engineer.

Thomas Palasek, Research Assistant, Engineer.

RELATED CONTRACTS AND PUBLICATIONS

F19628-74-C-0042	1 September 1973 through 31 July 1976.
F19628-76-C-0256	1 August 1976 through 31 October 1978.
F19628-78-C-0218	15 September 1978 through present.

Sukys, R. and Goldberg, S. (1974), Control Circuits for a Rocket Payload Neutralization and Other Topics", AFCRL-TR-74-0580.

Sukys, R., Rochefort, J.S. and Goldberg, S. (1975), "Bias and Signal Processing Circuits for a Mass Spectrometer in the Project EXCEDE: SWIR Experiment," AFGL-TR-76-200.

Rochefort, J. S. and Sukys, R. (1976), "Instrumentation Systems for Mass Spectrometers", AFGL-TR-76-200.

Rochefort, J. S. and Sukys, R. (1978), "A Digital Control Unit for a Rocket Borne Quadrupole Mass Spectrometer, AFGL-TR-78-0106.

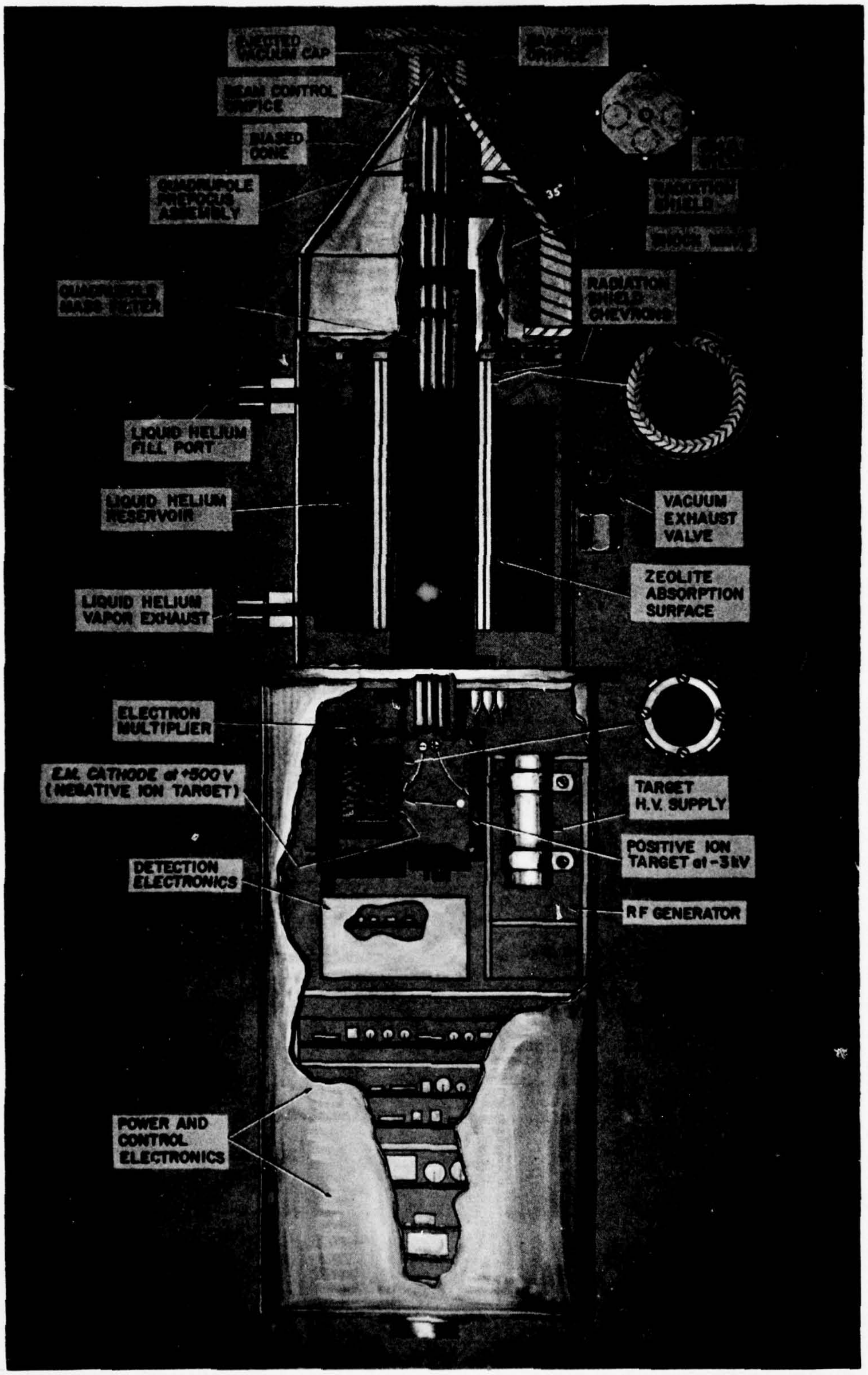


FIGURE 1. CLUSTER ION MASS SPECTROMETER
(Courtesy of Aeronomy Division of AFGL)

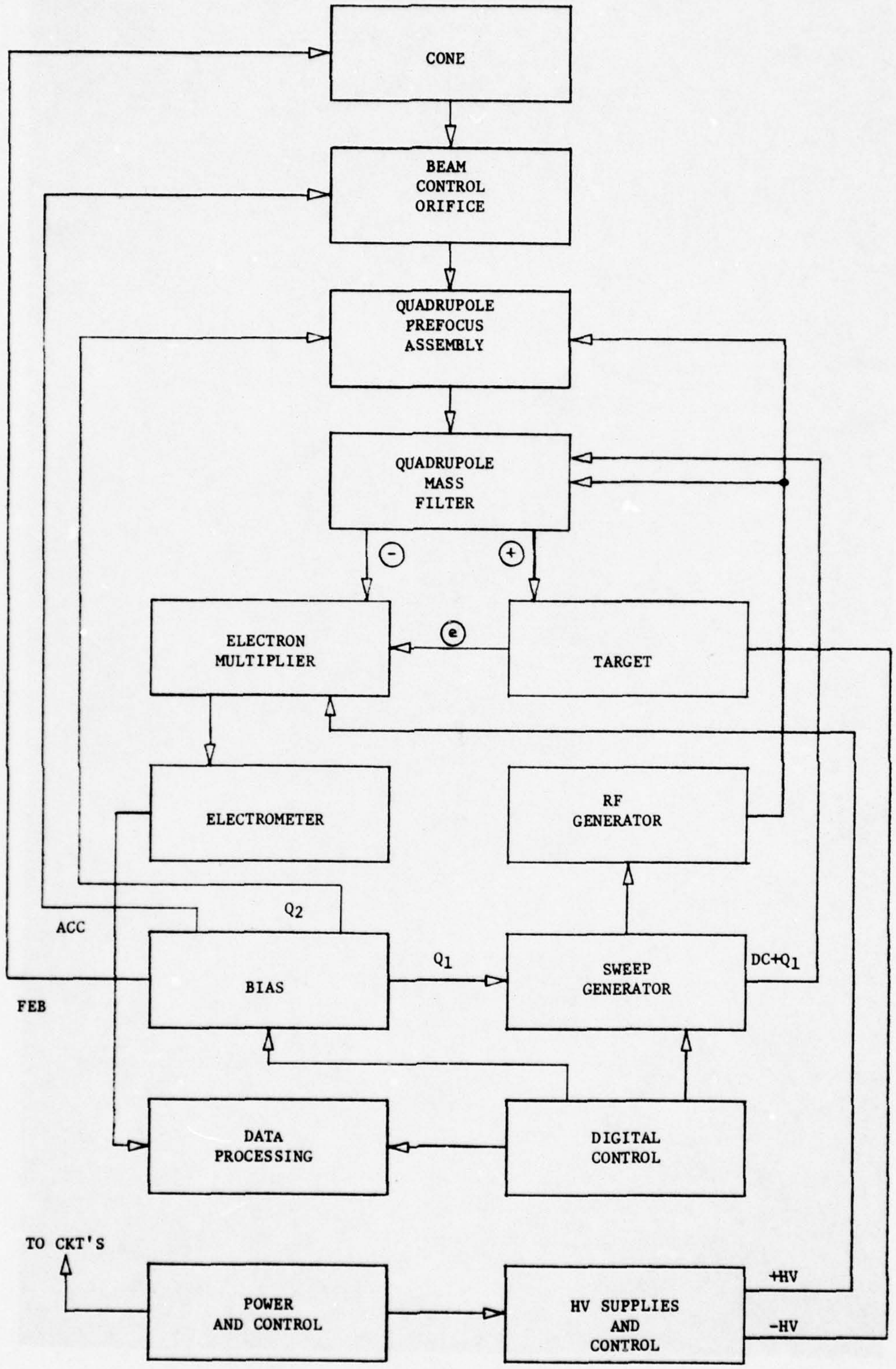
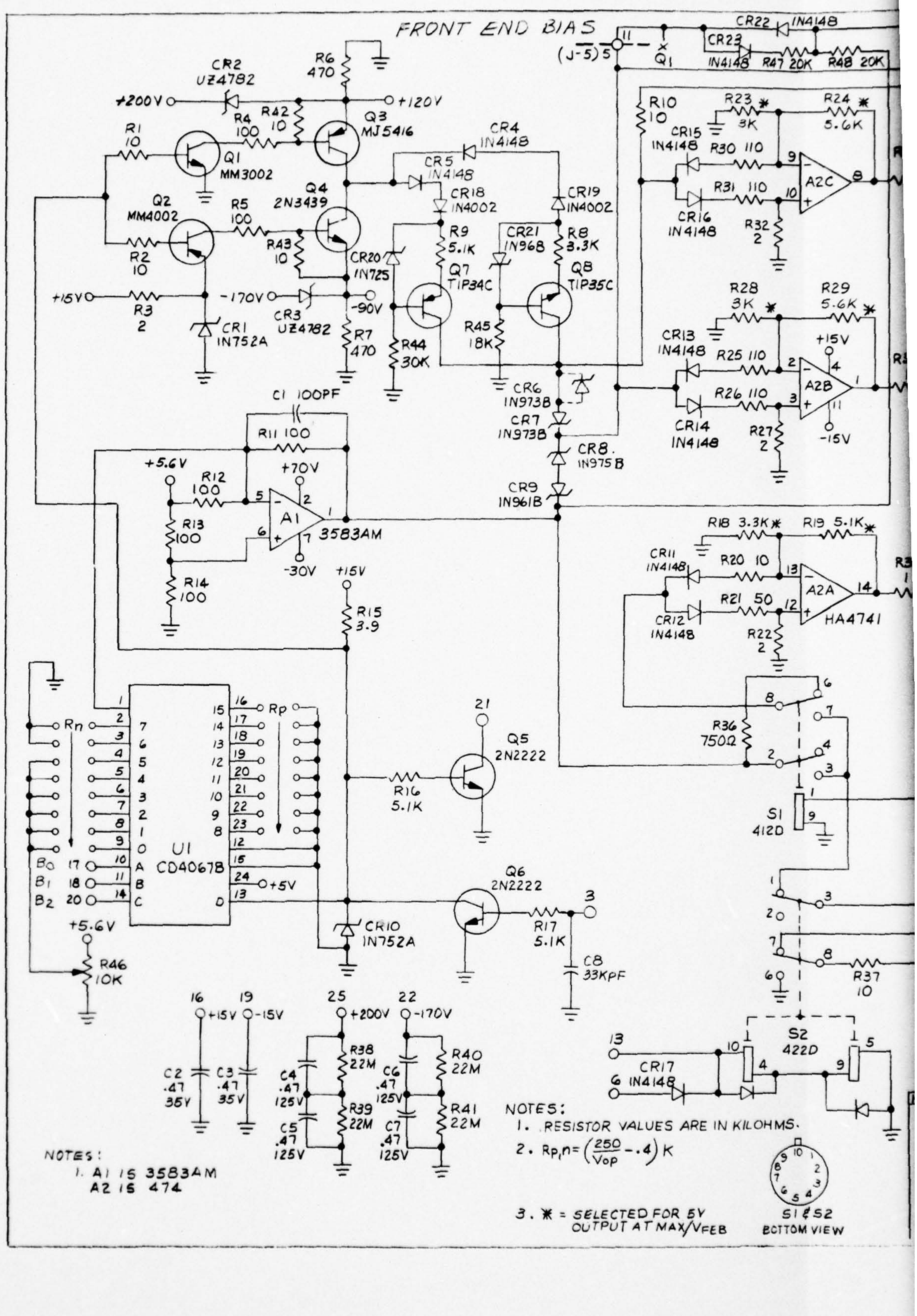


FIGURE 2. ELECTRONICS BLOCK DIAGRAM



FRONT END BIAS
(J-5)
Q1 MM3002
Q2 MM4002
Q3 MJ5416
Q4 2N3439
Q5 2N2222
Q6 2N2222
Q7 TIP34C
Q8 TIP35C
A1 3583AM
A2A HA4741
A2B
A2C
U1 CD4067B
S1 412D
S2 422D
+200V
+120V
+15V
-170V
-90V
+5.6V
+70V
-30V
+5V
-15V
C1 100PF
C2 .47 35V
C3 .47 35V
C4 .47 125V
C5 .47 125V
C6 .47 125V
C7 .47 125V
C8 33KPF
R46 10K
R36 750Ω
NOTES:
1. A1 IS 3583AM
A2 IS 474
NOTES:
1. RESISTOR VALUES ARE IN KILOHMS.
2. $R_{p,n} = \left(\frac{250}{V_{op}} - .4\right)K$
3. ✱ = SELECTED FOR 5V OUTPUT AT MAX/VFEB
S1 & S2 BOTTOM VIEW

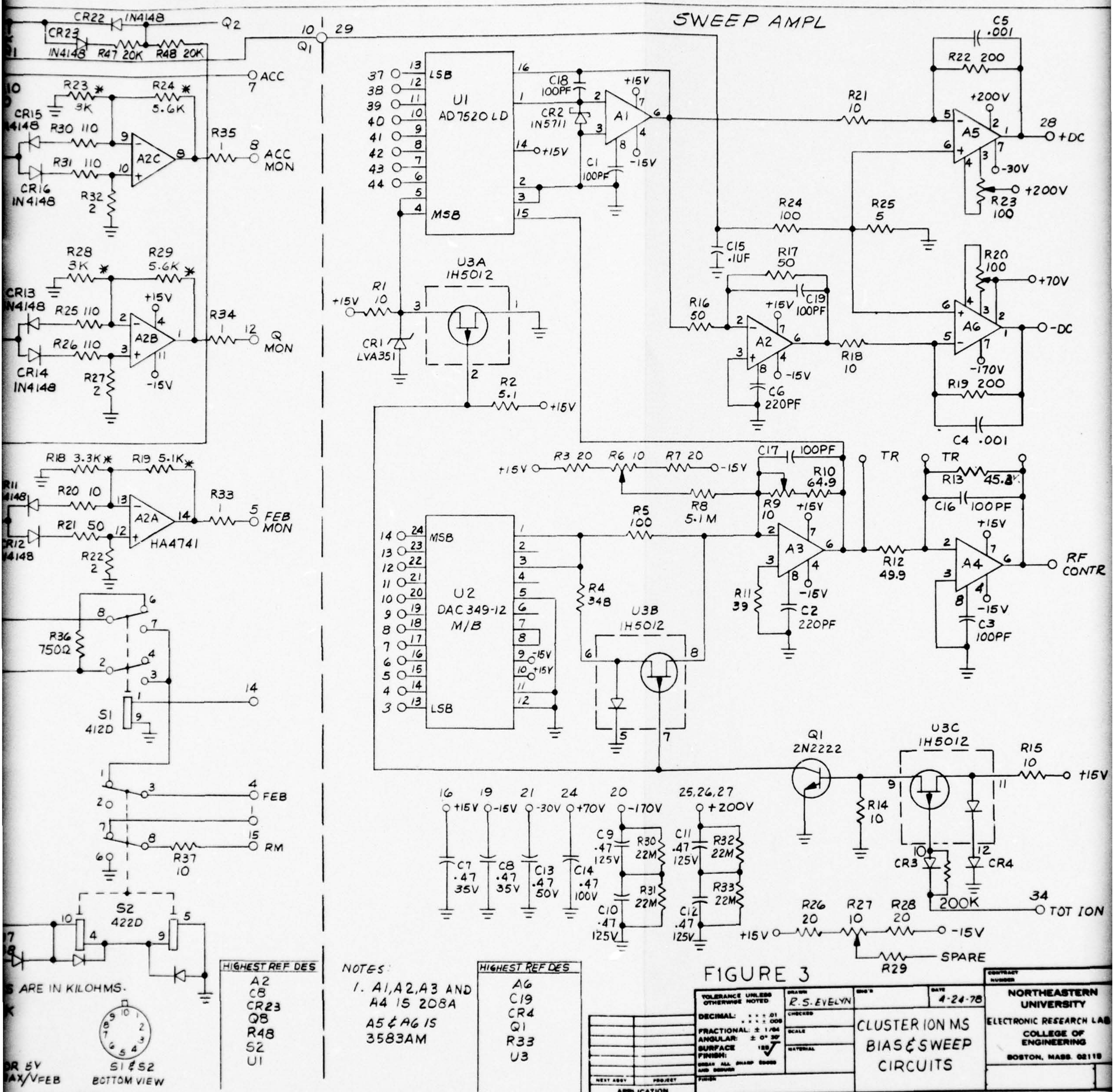

SWEEP AMPL
U1 AD7520LD
U2 DAC 349-12 M/B
U3A 1H5012
U3B 1H5012
U3C 1H5012
Q1 2N2222
A1
A2
A3
A4
A5
A6
A2A HA4741
A2B
A2C
ACC
ACC MON
Q MON
FEB MON
FEB
RM
+DC
-DC
RF CONTR
TOT ION
SPARE
S1 412D
S2 422D
S1 & S2 BOTTOM VIEW
ARE IN KILOHMS.
HIGHEST REF DES
A2
C8
CR23
Q8
R48
S2
U1
NOTES:
1. A1,A2,A3 AND A4 IS 208A
A5 & A6 IS 3583AM
HIGHEST REF DES
A6
C19
CR4
Q1
R33
U3
FIGURE 3
R. S. EVELYN
4-24-78
CLUSTER ION MS BIAS & SWEEP CIRCUITS
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
BOSTON, MASS. 02115
APPLICATION

FIGURE 3.

2

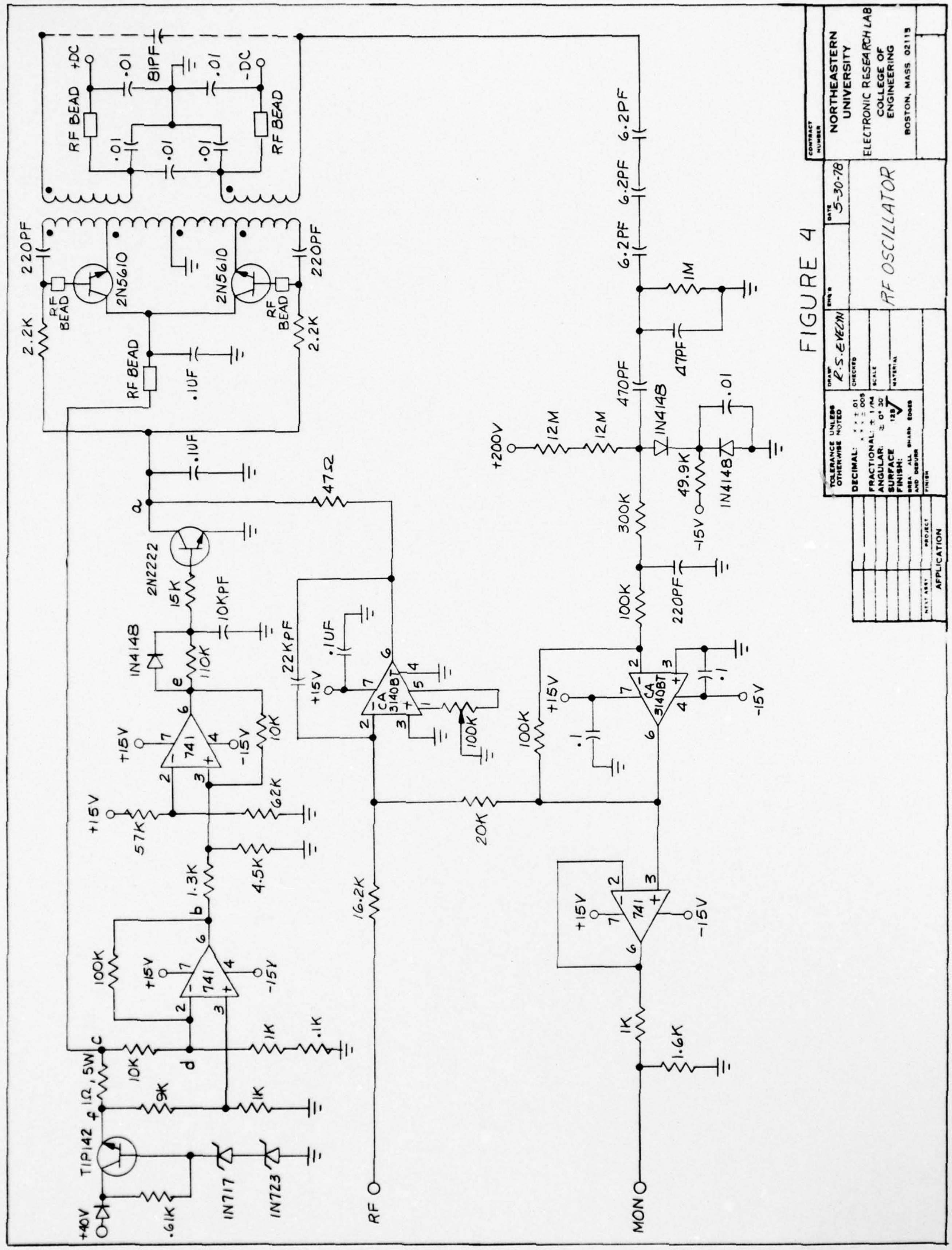
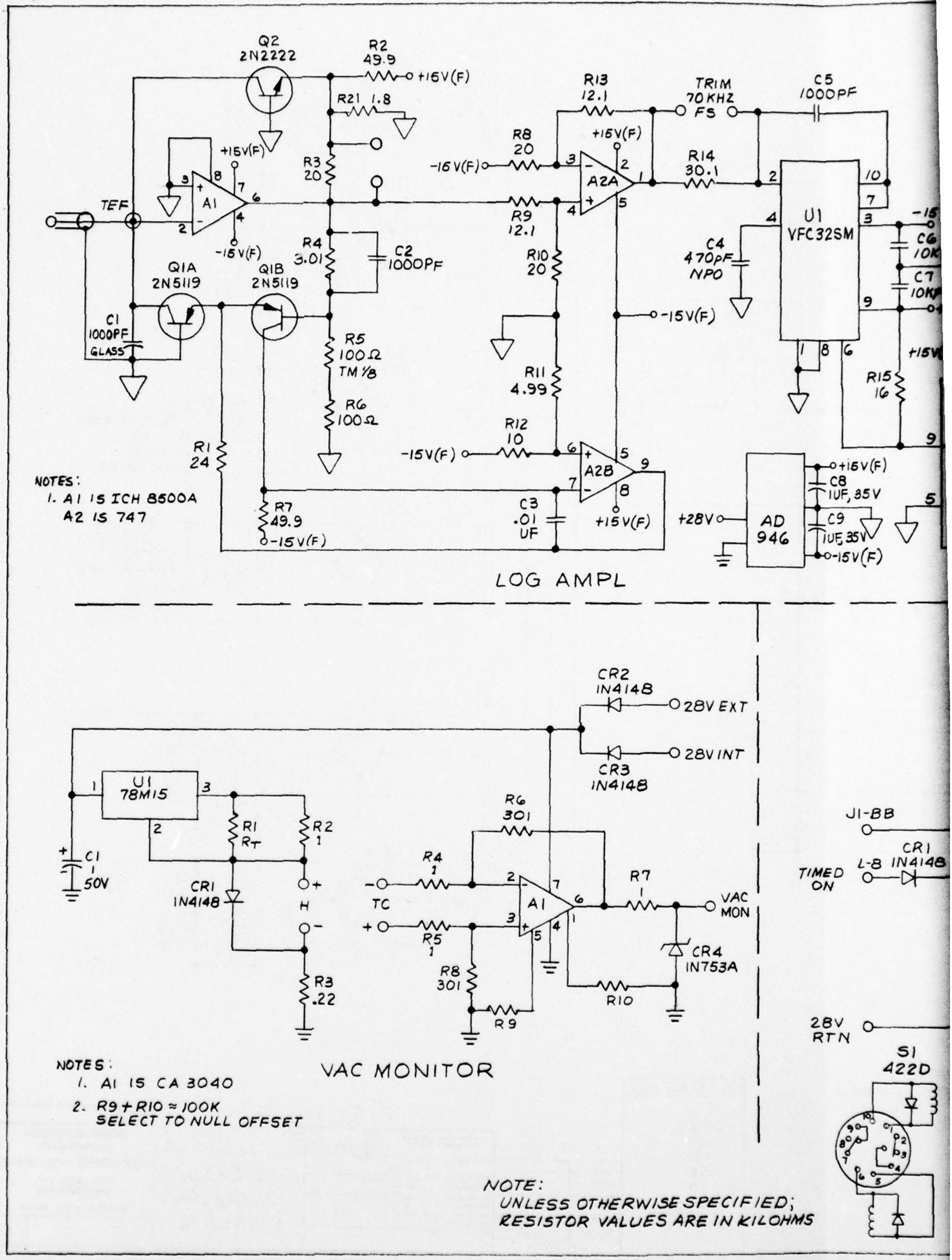
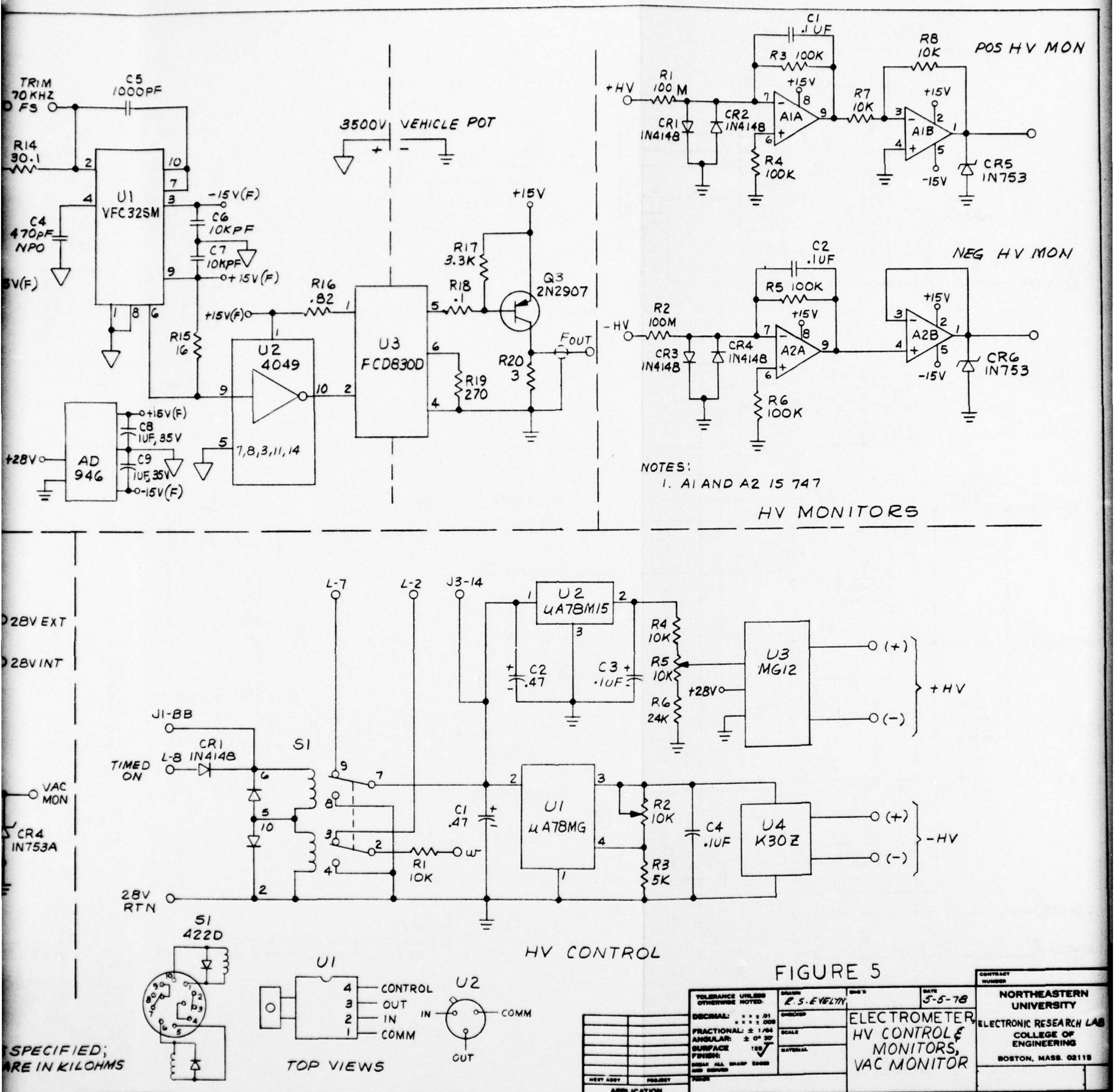


FIGURE 4
RF OSCILLATOR
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
BOSTON, MASS 02115
R.S. EVELYN
5-30-78
2N5610
2N2222
TIP142
RF BEAD
+40V
+200V
RF
MON

FIGURE 4


LOG AMPL
NOTES:
1. A1 IS ICH 8500A
A2 IS 747
Q2 2N2222
Q1A 2N5119
Q1B 2N5119
U1 VFC32SM
AD 946
TRIM 70KHZ FS
VAC MONITOR
NOTES:
1. A1 IS CA 3040
2. R9 + R10 ≈ 100K
SELECT TO NULL OFFSET
U1 78M15
CR2 1N4148
CR3 1N4148
28V EXT
28V INT
VAC MON
J1-BB
TIMED ON
28V RTN
S1 422D
NOTE:
UNLESS OTHERWISE SPECIFIED;
RESISTOR VALUES ARE IN KILOHMS

1



HV MONITORS
POS HV MON
NEG HV MON
NOTES:
1. A1 AND A2 IS 747
3500V VEHICLE POT
HV CONTROL
TOP VIEWS
SPECIFIED;
ARE IN KILOHMS
FIGURE 5
ELECTROMETER HV CONTROL & MONITORS, VAC MONITOR
R. S. EVELYN
5-5-78
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
BOSTON, MASS. 02115
APPLICATION

FIGURE 5.

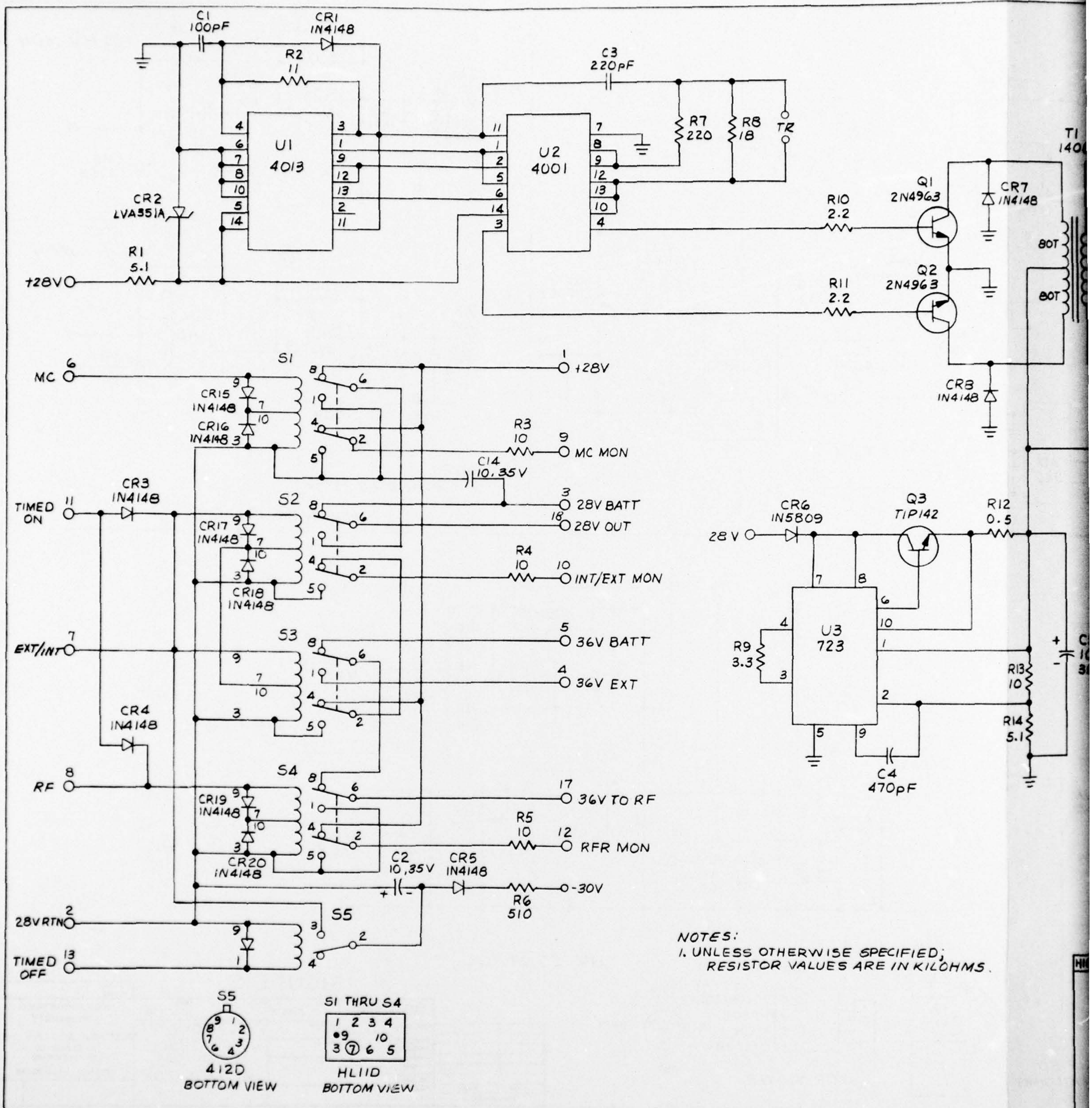
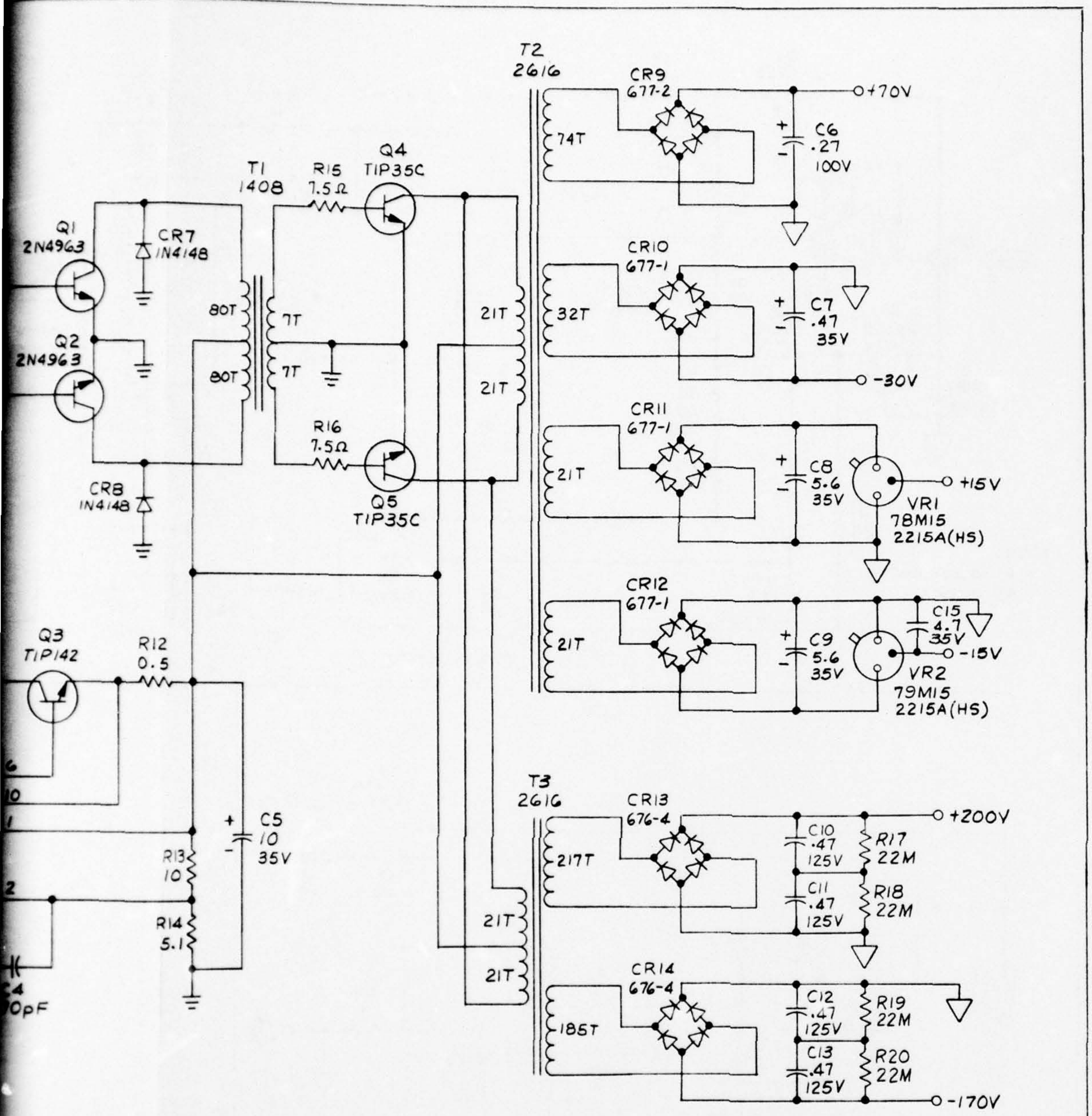

C1
100pF
CR1
1N4148
R2
11
C3
220pF
U1
4013
U2
4001
R7
220
R8
18
TR
T1
140
CR2
LVA351A
R1
5.1
+28V
R10
2.2
Q1
2N4963
CR7
1N4148
80T
80T
R11
2.2
Q2
2N4963
MC
S1
CR15
1N4148
CR16
1N4148
+28V
R3
10
MC MON
C14
10,35V
TIMED ON
CR3
1N4148
S2
CR17
1N4148
CR18
1N4148
28V BATT
28V OUT
R4
10
INT/EXT MON
CR8
1N4148
CR6
1N5809
Q3
TIP142
R12
0.5
28 V
U3
723
R9
3.3
R13
10
R14
5.1
C4
470pF
EXT/INT
S3
36V BATT
36V EXT
CR4
1N4148
RF
S4
CR19
1N4148
CR20
1N4148
36V TO RF
R5
10
RFR MON
C2
10,35V
CR5
1N4148
R6
510
-30V
28V RTN
S5
TIMED OFF
NOTES:
1. UNLESS OTHERWISE SPECIFIED; RESISTOR VALUES ARE IN KILOHMS.
S5
412D
BOTTOM VIEW
S1 THRU S4
HL11D
BOTTOM VIEW

FIGURE 6.



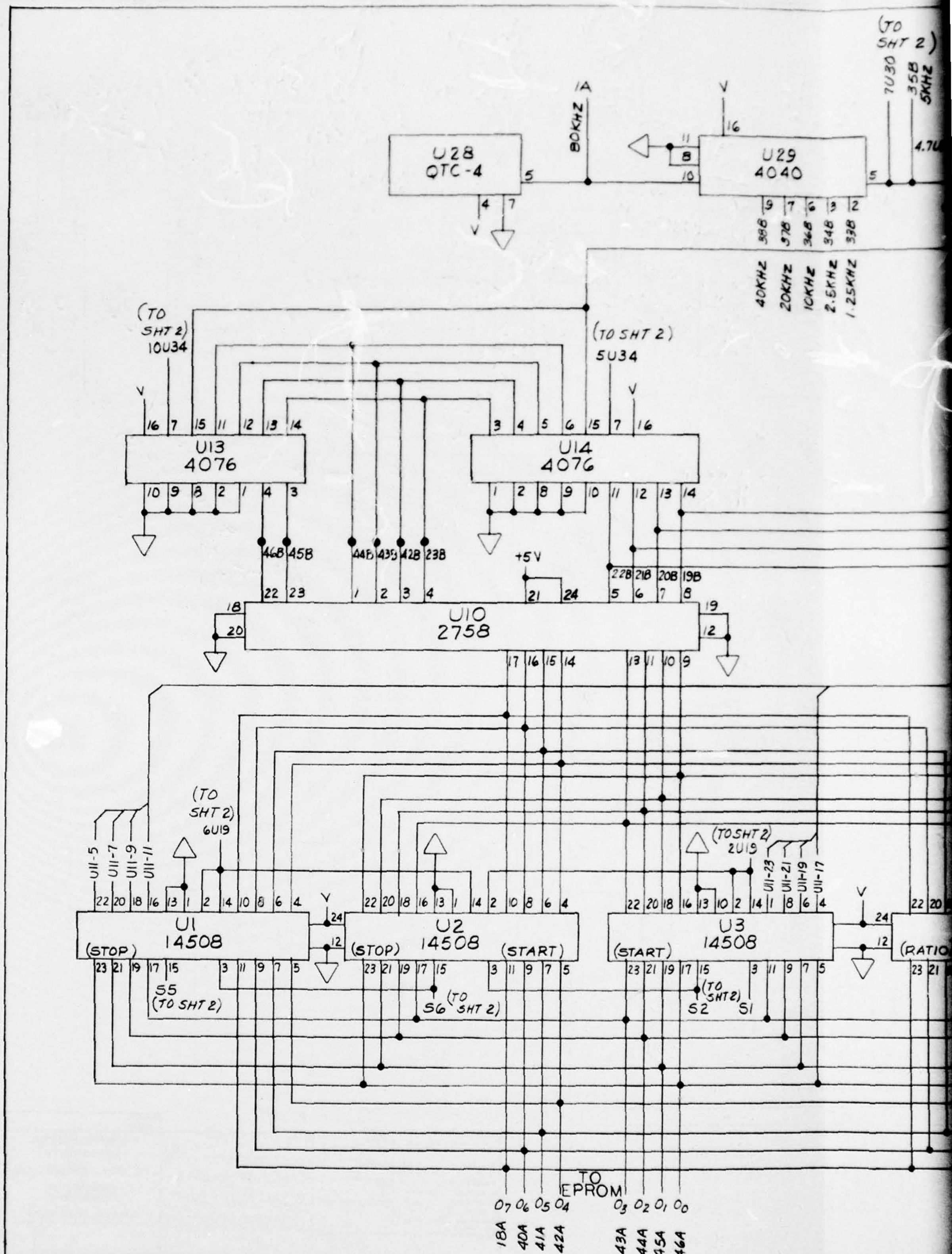
CIFIED;
IN KILOHMS.

HIGHEST REF DES
C15
CR20
Q5
R20
S5
T3
U3
VR2

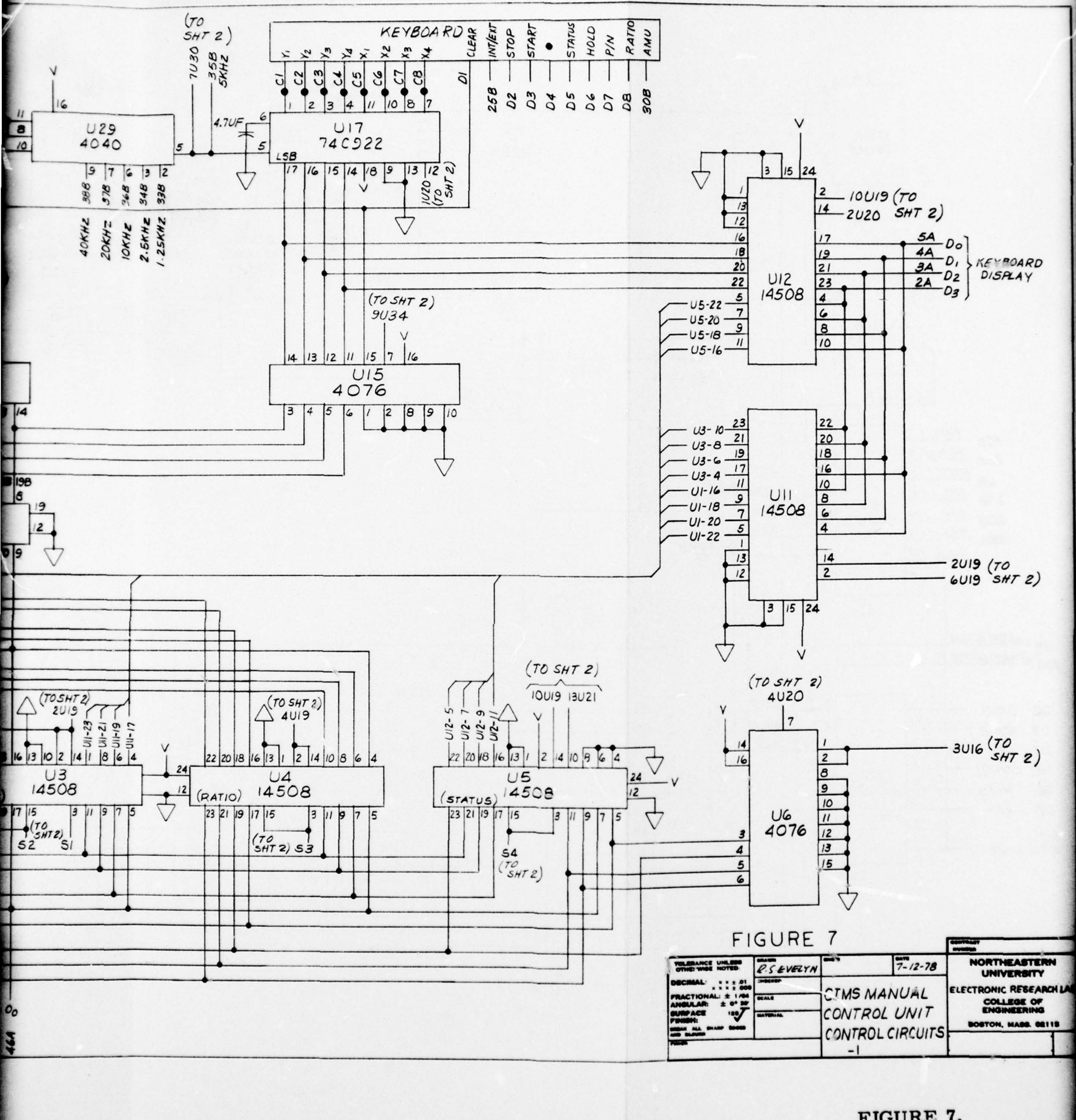
FIGURE 6

TOLERANCE UNLESS OTHERWISE NOTED DECIMAL: .XX ± .01, .XXX ± .005 FRACTIONAL: ± 1/64 ANGULAR: ± 0° 30' SURFACE FINISH: 125 BREAK ALL SHARP EDGES AND BURRS	DRAWN R. S. EVELYN / CHECKED / SCALE / MATERIAL	DATE 4-27-78 CLUSTER ION MS POWER SUPPLY & RELAYS
NEXT ASSY / PROJECT — APPLICATION	FINISH	NORTHEASTERN UNIVERSITY ELECTRONICS RESEARCH LAB COLLEGE OF ENGINEERING BOSTON, MASS. 02115

2



U28
QTC-4
80KHZ
1A
U29
4040
(TO SHT 2)
7U30
35B
5KHZ
40KHZ
20KHZ
10KHZ
2.5KHZ
1.25KHZ
38B
37B
36B
34B
33B
(TO SHT 2)
10U34
(TO SHT 2)
5U34
U13
4076
U14
4076
46B
45B
44B
43B
42B
23B
+5V
22B
21B
20B
19B
U10
2758
U11-5
U11-7
U11-9
U11-11
(TO SHT 2)
6U19
U1
14508
(STOP)
S5
(TO SHT 2)
U2
14508
(STOP)
(START)
S6
(TO SHT 2)
(TO SHT 2)
2U19
U11-23
U11-21
U11-19
U11-17
U3
14508
(START)
S2
(TO SHT 2)
S1
(RATIO
TO
EPROM
O_7 O_6 O_5 O_4
O_3 O_2 O_1 O_0
18A
40A
41A
42A
43A
44A
45A
46A



KEYBOARD
CLEAR
INT/EXT
STOP
START
STATUS
HOLD
P/N
RATIO
AMU
U29
4040
U17
74C922
4.7UF
LSB
40KHZ
20KHZ
10KHZ
2.5KHZ
1.25KHZ
U15
4076
U12
14508
U11
14508
KEYBOARD DISPLAY
U3
14508
U4
14508
(RATIO)
U5
14508
(STATUS)
U6
4076
(TO SHT 2)
FIGURE 7
R.S.EVELYN
7-12-78
CTMS MANUAL
CONTROL UNIT
CONTROL CIRCUITS
-1
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
BOSTON, MASS. 02115

FIGURE 7.

2

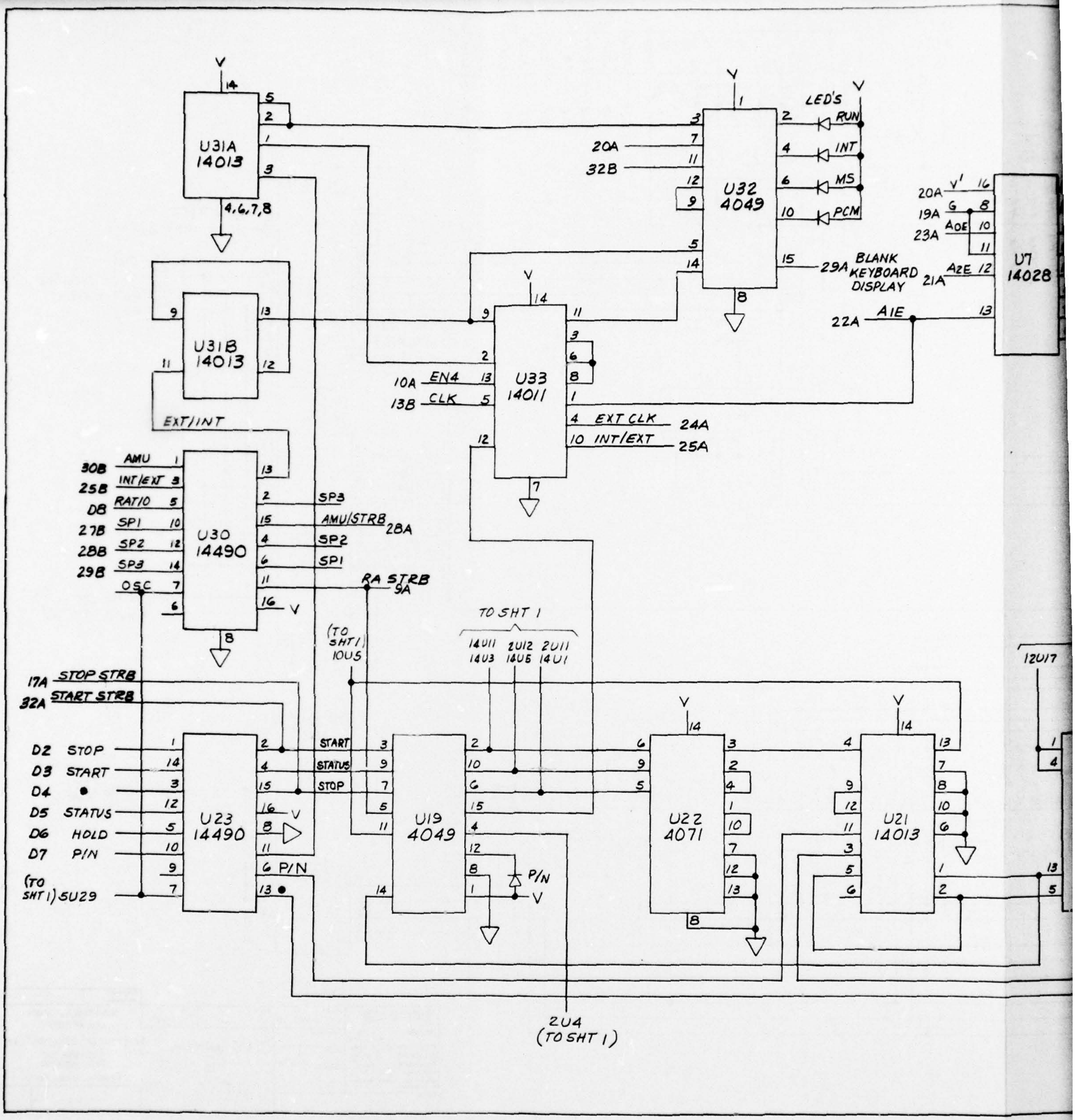

U31A
14013
U31B
14013
U30
14490
U32
4049
U33
14011
U7
14028
U23
14490
U19
4049
U22
4071
U21
14013
LED'S
RUN
INT
MS
PCM
BLANK
KEYBOARD
DISPLAY
EXT/INT
AMU
INT/EXT
RATIO
SP1
SP2
SP3
OSC
AMU/STRB
RA STRB
EN4
CLK
EXT CLK
INT/EXT
A1E
A0E
A2E
STOP STRB
START STRB
D2 STOP
D3 START
D4
D5 STATUS
D6 HOLD
D7 P/N
(TO SHT 1) 5U29
START
STATUS
STOP
P/N
TO SHT 1
(TO SHT 1) 10U5
2U4
(TO SHT 1)
12U17

FIGURE 8.

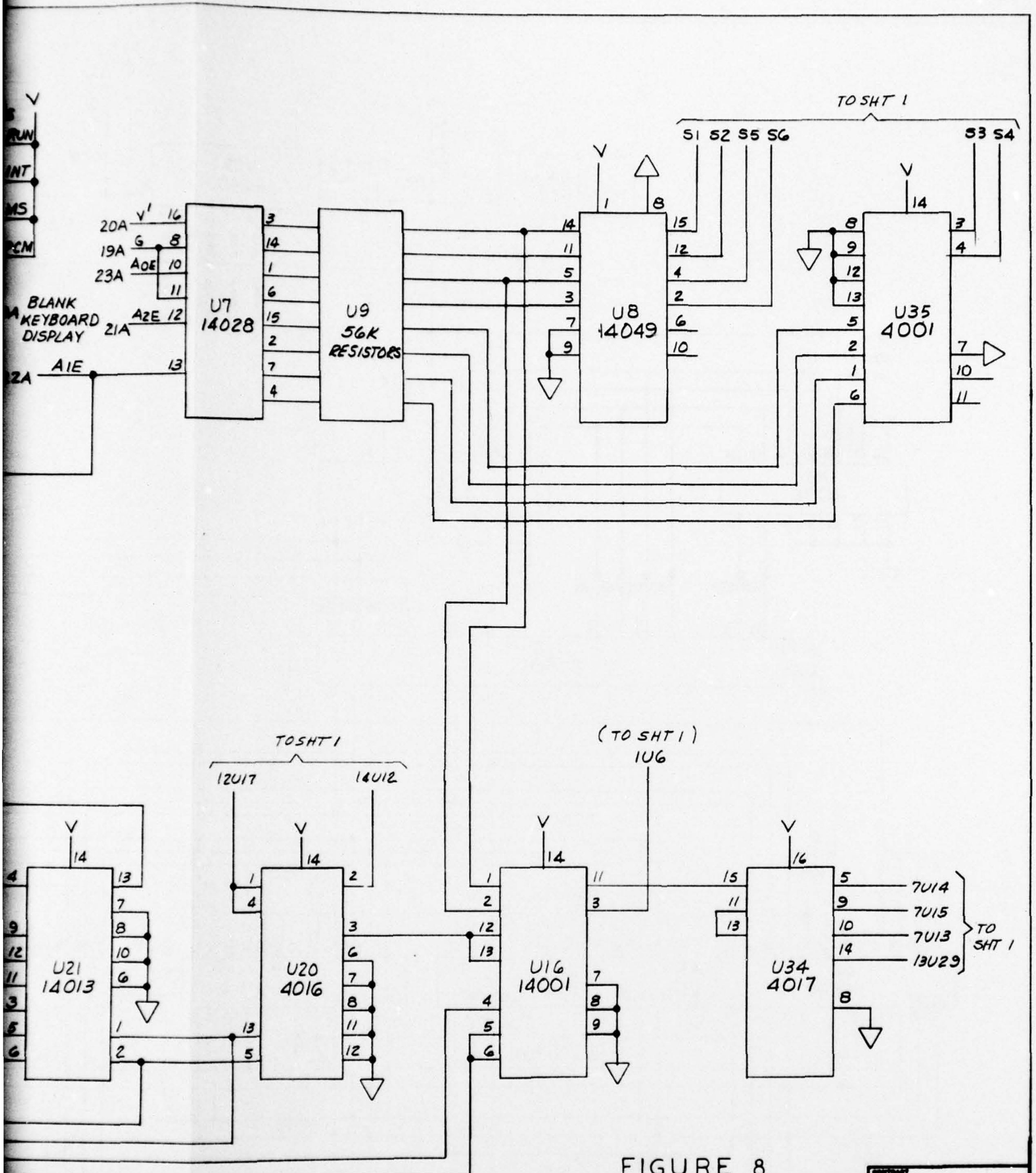
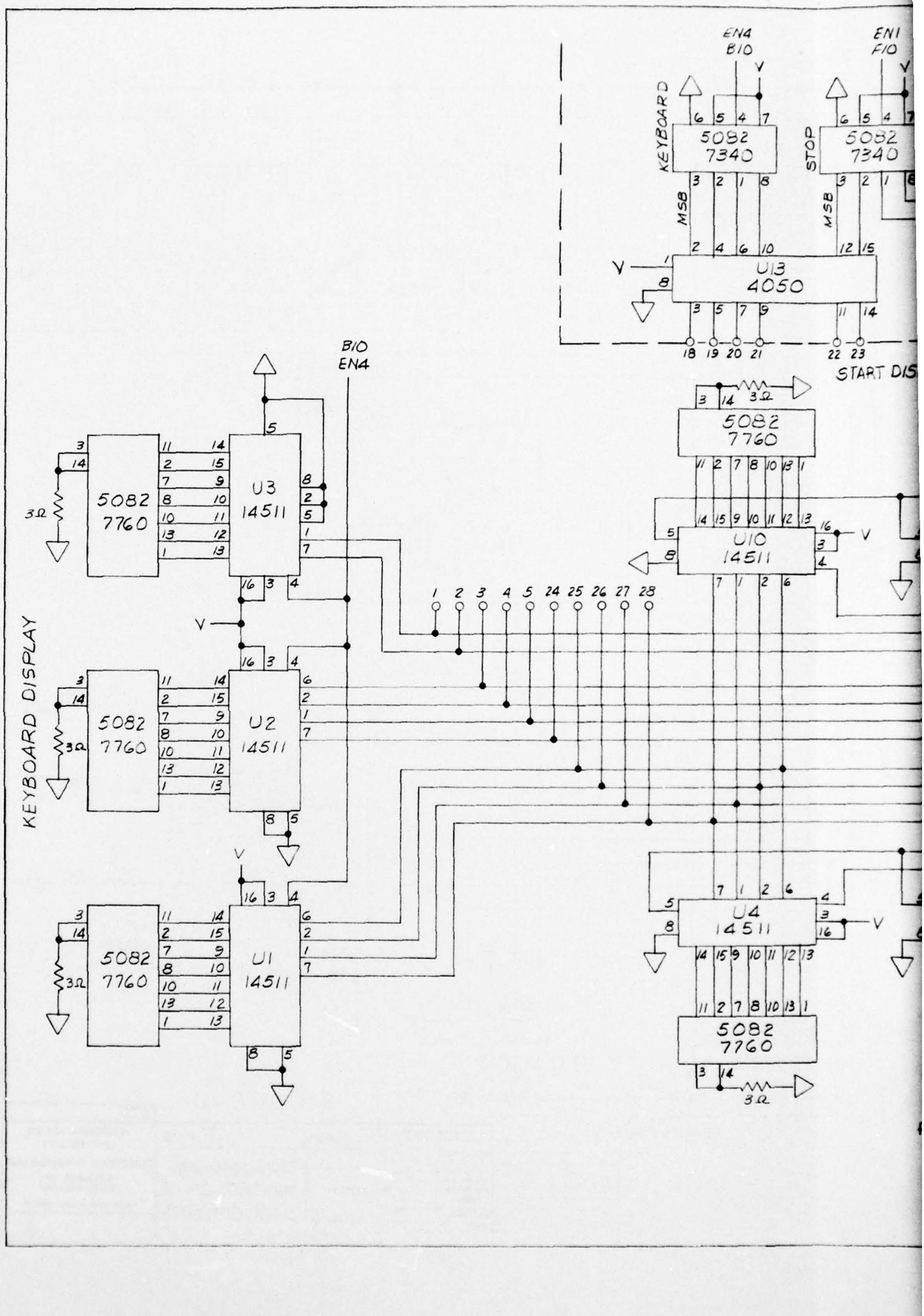


FIGURE 8

TOLERANCE UNLESS OTHERWISE NOTED: DECIMAL: .XX ± .01, .XXX ± .005; FRACTIONAL: ± 1/64; ANGULAR: ± 0° 30'; SURFACE FINISH: 125	DRAWN R.S. EVELYN	ENG'R	DATE 7-12-78
	CHECKED / SCALE / MATERIAL	CIMS MANUAL CONTROL UNIT CONTROL CIRCUITS -2	NORTHEASTERN UNIVERSITY ELECTRONIC RESEARCH LAB COLLEGE OF ENGINEERING BOSTON, MASS. 02115

2


KEYBOARD DISPLAY
5082 7760
U3 14511
U2 14511
U1 14511
B/O EN4
V
3Ω
KEYBOARD
STOP
5082 7340
MSB
EN4 B/O
EN1 F/O
U13 4050
U10 14511
U4 14511
START DIS

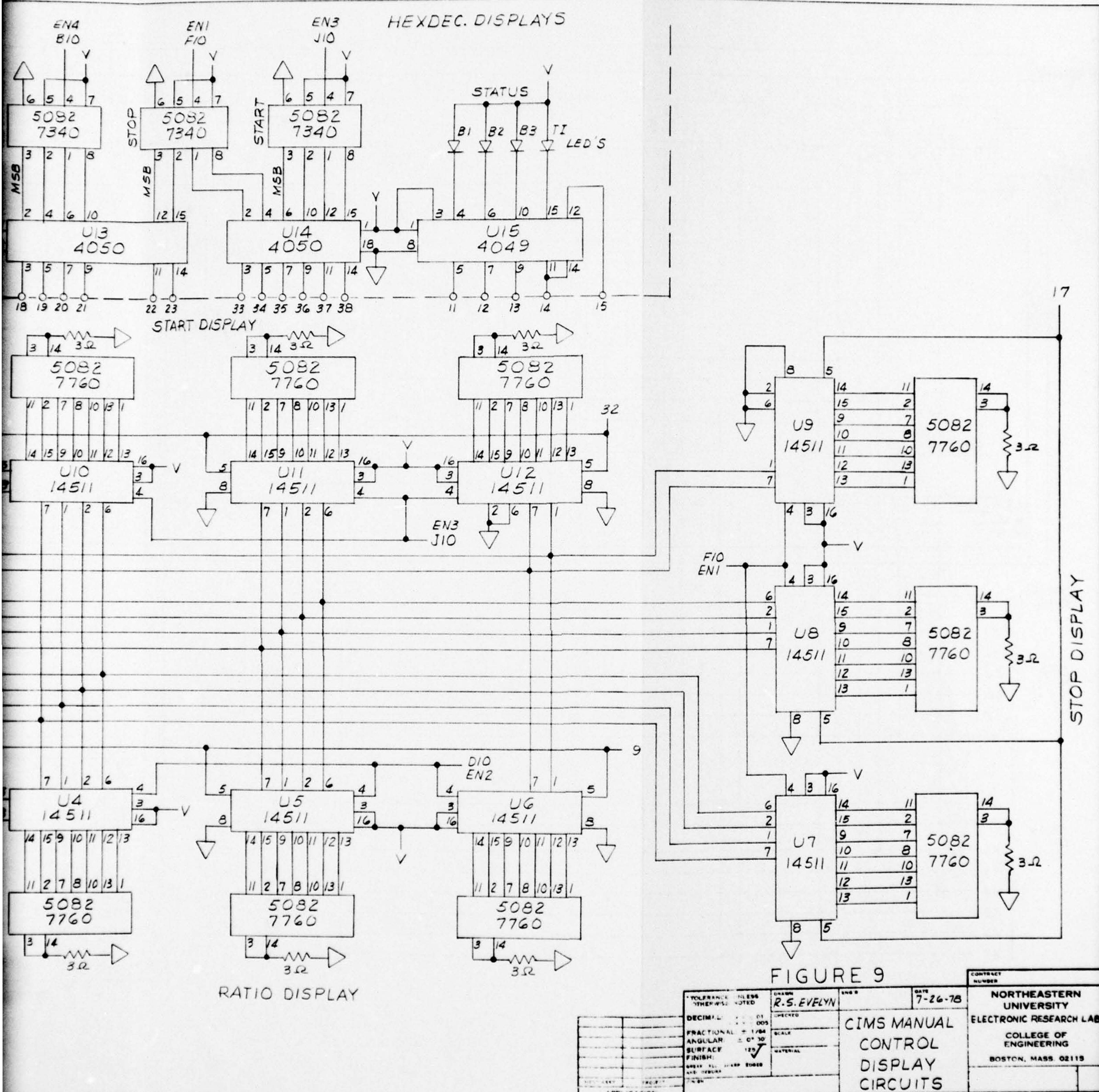

HEXDEC. DISPLAYS
EN4 B10
EN1 F10
EN3 J10
STATUS
B1 B2 B3 T1 LED'S
5082 7340
STOP
START
MSB
U13 4050
U14 4050
U15 4049
START DISPLAY
5082 7760
U10 14511
U11 14511
U12 14511
EN3 J10
U9 14511
F10 EN1
U8 14511
D10 EN2
U4 14511
U5 14511
U6 14511
U7 14511
3Ω
STOP DISPLAY
RATIO DISPLAY
FIGURE 9
R.S. EVELYN
7-26-78
CIMS MANUAL CONTROL DISPLAY CIRCUITS
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
BOSTON, MASS. 02115
APPLICATION

FIGURE 9.

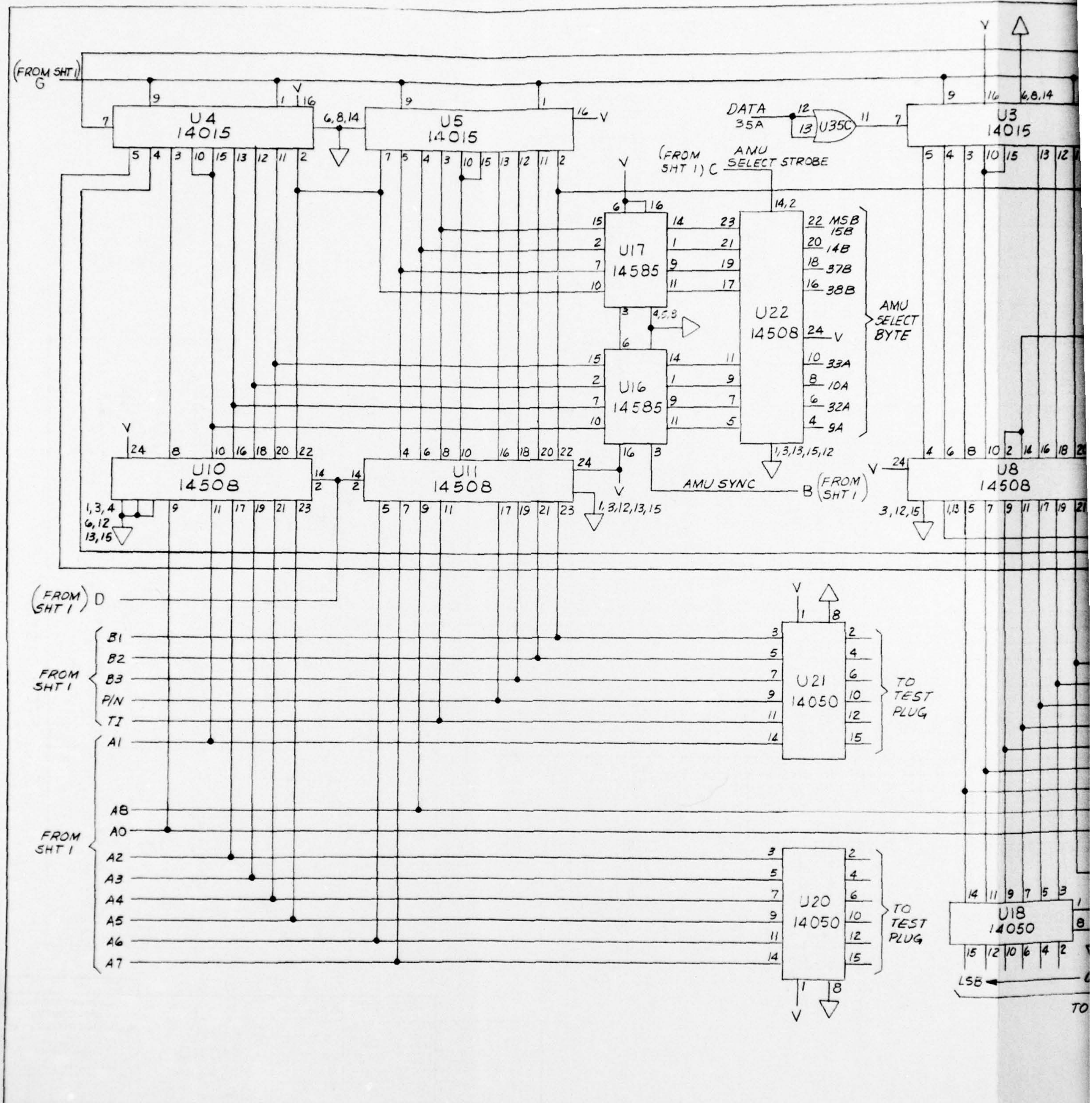

(FROM SHT 1) G
U4 14015
U5 14015
U3 14015
DATA 35A
U35C
(FROM SHT 1) C
AMU SELECT STROBE
U17 14585
U16 14585
U22 14508
MSB 15B
14B
37B
38B
AMU SELECT BYTE
33A
10A
32A
9A
U10 14508
U11 14508
U8 14508
AMU SYNC
B (FROM SHT 1)
(FROM SHT 1) D
FROM SHT 1
B1
B2
B3
P/N
T1
A1
A8
A0
A2
A3
A4
A5
A6
A7
U21 14050
TO TEST PLUG
U20 14050
TO TEST PLUG
U18 14050
LSB

FIGURE 10.

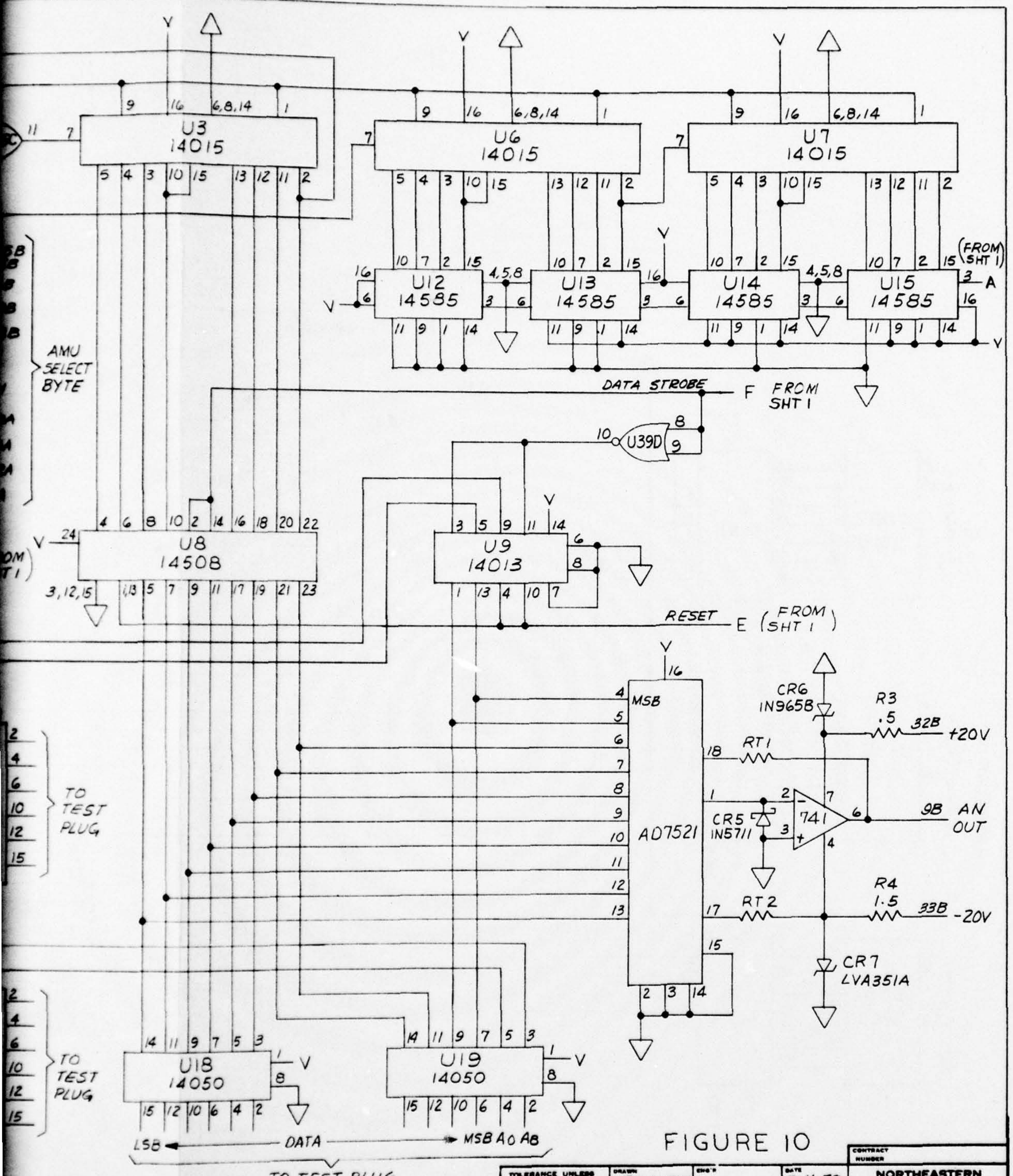
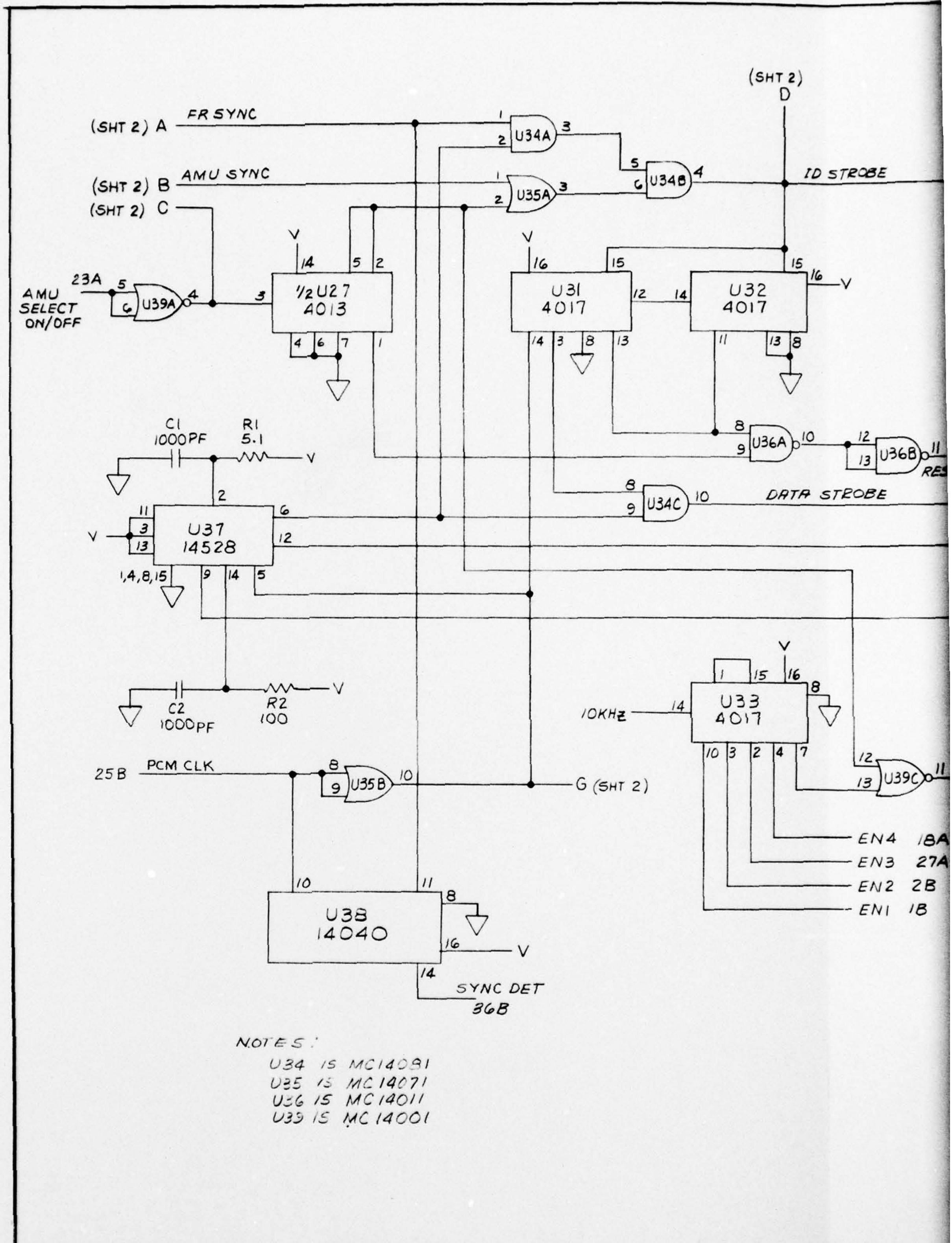
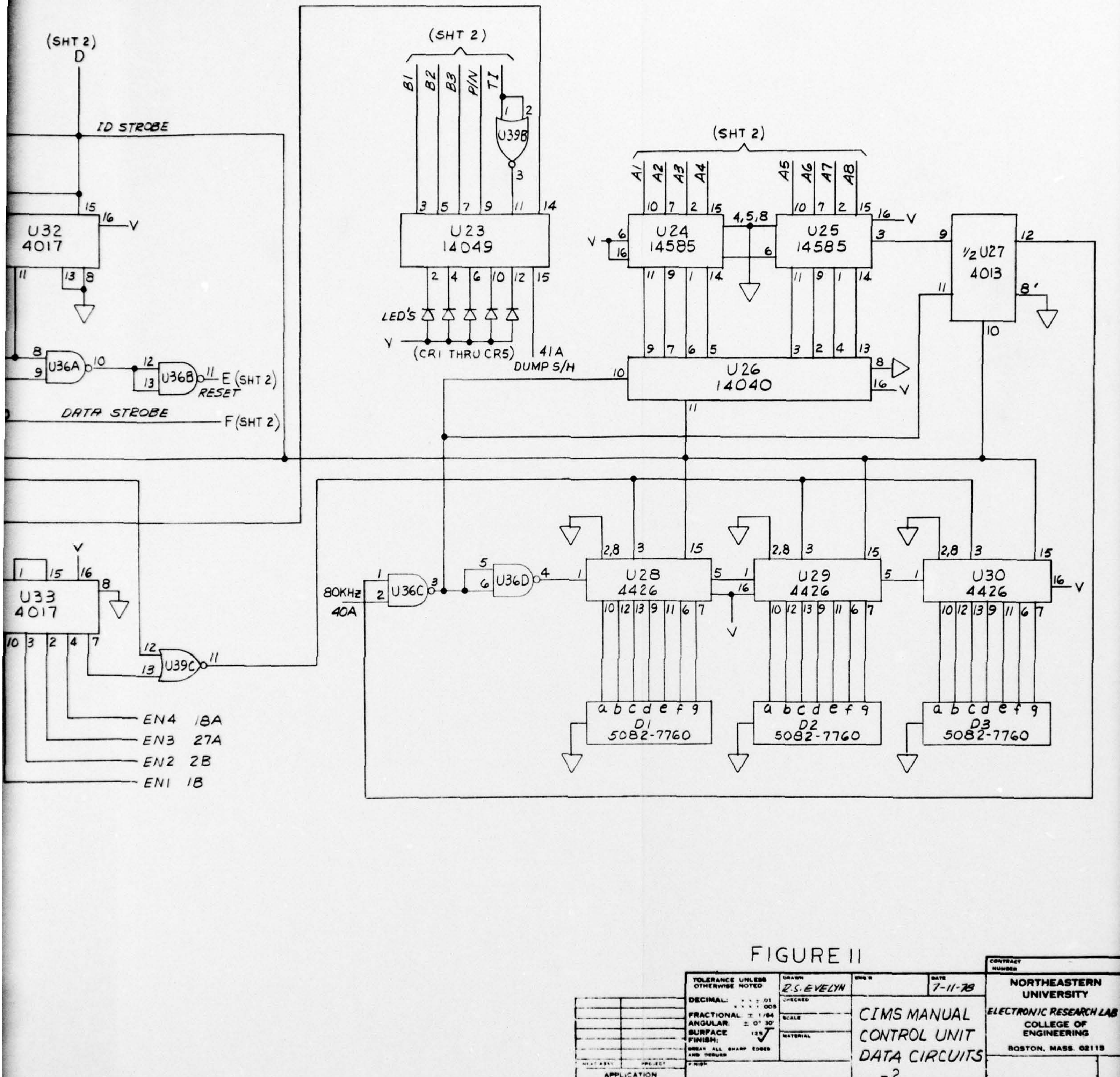


FIGURE 10

TOLERANCE UNLESS OTHERWISE NOTED DECIMAL: ± .01 ± .005 FRACTIONAL: ± 1/64 ANGULAR: ± 0° 30' SURFACE FINISH: 125 BREAK ALL SHARP EDGES AND DEBURR FINISH	DRAWN R.S. EVELYN CHECKED SCALE MATERIAL	ENG'R DATE 7-11-78
NEXT ASSY / PROJECT APPLICATION	CIMS MANUAL CONTROL UNIT DATA CIRCUITS -1	CONTRACT NUMBER NORTHEASTERN UNIVERSITY ELECTRONIC RESEARCH LAB COLLEGE OF ENGINEERING BOSTON, MASS. 02115


(SHT 2) A
FR SYNC
(SHT 2) B
AMU SYNC
(SHT 2) C
(SHT 2)
D
U34A
U34B
U35A
ID STROBE
AMU
SELECT
ON/OFF
23A
U39A
1/2 U27
4013
U31
4017
U32
4017
U36A
U36B
C1
1000PF
R1
5.1
U37
14528
U34C
DATA STROBE
C2
1000PF
R2
100
U33
4017
10KHz
25B
PCM CLK
U35B
G (SHT 2)
U39C
EN4 18A
EN3 27A
EN2 2B
EN1 1B
U38
14040
SYNC DET
36B
NOTES:
U34 IS MC14081
U35 IS MC14071
U36 IS MC14011
U39 IS MC14001


(SHT 2) D
ID STROBE
U32 4017
U33 4017
U36A
U36B
E (SHT 2) RESET
DATA STROBE
F (SHT 2)
(SHT 2)
B1 B2 B3 P/N TI
U39B
U23 14049
LED'S
(CR1 THRU CR5)
41A DUMP S/H
(SHT 2)
A1 A2 A3 A4
A5 A6 A7 A8
U24 14585
U25 14585
4,5,8
1/2 U27 4013
U26 14040
80KHz 40A
U36C
U36D
U39C
U28 4426
U29 4426
U30 4426
D1 5082-7760
D2 5082-7760
D3 5082-7760
EN4 18A
EN3 27A
EN2 2B
EN1 1B
FIGURE 11
TOLERANCE UNLESS OTHERWISE NOTED
DECIMAL
FRACTIONAL ± 1/64
ANGULAR ± 0° 30'
SURFACE FINISH
DRAWN R.S. EVELYN
DATE 7-11-78
CIMS MANUAL CONTROL UNIT DATA CIRCUITS - 2
NORTHEASTERN UNIVERSITY
ELECTRONIC RESEARCH LAB
COLLEGE OF ENGINEERING
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APPLICATION

FIGURE 11.

2